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PJ.18-04b

IMPROVED MET INFORMATION

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Abstract

PJ.18-04b, Improved MET information develops component and information services for Solutions in the SESAR2020 Industrial Research (IR) Programme that has Meteorological Information (MET) need. This document summarizes the results from different validation exercises executed by PJ.18-04b partners and their respective prototypes and developments. Exercises have been conducted either together with their dependent solution or internally by PJ.18-04b.

Amongst all developments, PJ.18-04b proposes two TRL6 solutions at the end of Wave 1, these are:

- GWMS Enhancement coupled with the METforTAM service and glide wind profile capability
- Cb-global capability and service

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1 Executive summary

PJ.18-04b aims to design and develop improved MET services or capabilities that provide MET information contributing to enhanced situational awareness of information consumer. The activities of PJ.18-04b are organised with operational use in mind where most of the components are developed based on the need of operational solutions within the IR programme. PJ.18-04b has coordinated with solutions PJ.02-01, PJ03b-06, PJ.04-02, PJ05-05, PJ.18-04c and PJ24[1] which resulted in various specific MET requirements, subsequently developments of different nature serving different MET needs, but with a common objective: to improve the MET information provision.

Amongst all activities undertaken by PJ.18-04b, the following developments are considered as mature enough for implementation, therefore proposed as TRL6 solutions of PJ.18-04b for Wave 1.

- Solution 1: GWMS enhancement capability coupled with Glide Wind Profile capability and METForTAM service
- Solution 2: Cb-global capability and service

The remaining developments of PJ.18-04b are regarded as activities in support of other solutions and some of them are of lower maturity level that require further research.

This document presents the results of all technical validation exercises performed by PJ.18-04b in order to provide a comprehensive view of all developments. As a result, the TVALR contains results of validation exercises with different maturity levels. However it should be emphasised that only the results of TRL6 exercises are considered as mature and being part of the solution that PJ.18-04b proposes. Following the dependencies established with other ATM solutions, several PJ.18-04b components have been integrated and validated by the ATM solutions they support (e.g. PJ24).

The main objective of the technical validations is to ensure that the developed prototypes are “fit for purpose” in view of their potential incorporation in various ATM systems, serving various ATM operational objectives expressed by the ATM Solutions. Technical validation therefore should be considered to validate the components on its operational usability in terms of providing the users (represented in an operational validation exercise) an indication of the confidence they will be able to place in the served information.

For the two solutions that is proposed by PJ.18-04b, the following TRL6 validation exercises have been performed:

- EXE-18-04b-TRL6-001_LDO [Solution 1]
- EXE-18-04b-TRL6-004_LDO [Solution 1]
- EXE-18-04b-TRL6-005_LDO [Solution 1]
- EXE-18-04b-TRL6-001_DLR [Solution 2]

[1] PJ.18-04b validation activities in support of PJ.24 demo are fully integrated in terms of deliverables.

- EXE-18-04b-TRL6-002_DLR [Solution 2]

PJ.18-04b has also performed the following validation exercises addressing the developed capabilities or information services. These are activities either in support of other ATM solutions or of lower maturity level which require further research before implementation, therefore not proposed as standalone solutions in the context of PJ.18-04b.

- EXE-18-04b-TRL2-002_LDO
- EXE-18-04b-TRL4-001_CCL
- EXE-18-04b-TRL4-002_CCL
- EXE-18-04b-TRL4-001_LPS SR
- EXE-18-04b-TRL4-002_LPS SR
- EXE-18-04b-TRL4-003_DLR
- Three additional integrated exercises in support of PJ.04-02, PJ05-05 and PJ24.

The capabilities and information services validated in these exercises are presented in the PJ.18-04b TVALP [40].

Depending on the context in which the prototypes are validated, by either ATM operation or PJ.18-04b, the adopted approaches range from technical feasibility assessment to real time emulation, all meant to achieve the main validation objective as described above.

Due to wide range of specific aspects that are addressed by the different developments, conclusions are drawn for each validation exercises in the respective Appendixes. In general, it can be concluded that the components have proven their technical feasibility and provided output as expected. The TRL6 developments have demonstrated high maturity that should be ready for future implementations.

Recommendations are listed for each validation exercise in the respective Appendixes. The key recommendations are to subject the prototypes to very large demonstrations with close to live scenarios to further refine the prototypes for implementation and to further align TRL6 prototypes with existing standards to prepare for future deployment.

2 Introduction

2.1 Purpose of the document

This document presents the technical validation report of all PJ.18-04b activities. The report consolidates validation results of the validation exercises described in the PJ.18-04b technical validation plan. It describes the activities that have been performed to meet the validate objectives, the exercises performed and the outcome.

Amongst all activities, PJ.18-04b proposes two solutions that have successfully completed the TRL6 validation exercises and considered mature enough for implementation. These are:

- Solution 1: GWMS enhancement linked with Glide wind profile capability and METForTAM service.
- Solution 2: Cb-global capability and service

In line with the PJ.18-04b TVALP, this document also includes the validation results of other capabilities and information services PJ.18-04b has developed. Some of these exercises have been conducted in coordination with the other solutions that PJ.18-04b supports and they are described in detail in the TVALP and this TVALR.

2.2 Intended readership

PJ.18-04b proposes two solutions and a range of activities with the objective to improve MET information provision that can be used in an operational context, thereby meeting the needs expressed by other SESAR 2020 solutions. As a means of collaboration, dependencies with other solution were established and activities undertaken by PJ.18-04b. It is therefore important that the solutions concerned are involved in the development and review of PJ.18-04b activities.

The intended readership of the present document is as follows:

- SJU to assess this SESAR 2020 deliverable.
- Partner solutions that had established dependency with PJ18-04b, i.e. PJ.02-01, PJ.03b-06, PJ.04-02, PJ.05-05, PJ.17-01 and PJ.18-04c
- Solution PJ18-04c which uses the results of the PJ18-04b output as they contribute to enhanced MET advisory information provision, in order to develop solutions which make available this information in the cockpit.
- Solution PJ19 in charge of Content Integration activity, which follows a collaborative and iterative process involving all SESAR 2020 Solutions.
- Any SESAR 2020 projects and solutions interested in the PJ.18-04b TRL6 technical validation activities or PJ.18-04c TRL4 technical validation activities about background information on components of enhanced MET information used in PJ18-04c.

2.3 Background

PJ.18-04b proposes two solutions for TRL6 maturity assessment. The solution related to GWMS enhancement followed the outcome of SESAR 1 and the solution related to Cb-global is new in the SESAR context.

This section provides the background of activities performed before that are relevant for the developments being addressed in Wave 1.

Part of the activities presented in this document is based on previous work done in SESAR 1 in Projects 15.04.09.c (Solution #21 Airport operations plan (AOP) and its seamless integration with the network operations plan (NOP) [54]) and 11.02.02 (Solution #35 MET information exchange [52]) from the MET perspective. In particular, the METForTAM service is based on work of OFA05.01.01 [55], the IERs of which have been adopted by Solution 04-02 in SESAR2020 wave 1, i.e. possibly new or changed requirements formulated in SESAR 2020 Wave 1 will be included as well. These requirements are the driver for the service payload of METForTAM. Additionally, as the GMWS output satisfying these requirements had been provided in a proprietary manner in EXE669 of OFA05.01.01, meaning that the requirements on SWIM compliance for the 4DWxCube TS in the Aerodrome ATM MET capability configuration that GWMS is prototyping had not been validated, yet, the development of METForTAM has a link to the task of GWMS Enhancement where the gap of the METGate functional block inside the Aerodrome ATM MET CC is closed and requirements still <in progress> are validated. The provision of METForTAM by GWMS has been prototyped to be SWIM Yellow Profile (YP) compliant using AMQP1.0 messaging. METForTAM service provision was included and validated in EXE-PJ.04-02-V2.04. This being a v2 exercise, METForTAM nevertheless is shown to be of TRL6 readiness, since the provision of the service has been based on an Emulation of MET sources (sensors and models) as if they were used in operations, using the actual operational interfaces and real archived data, i.e making it transparent to the GWMS whether the actual real time sources for Oslo Airport are attached or not. Since it is a general constraint for validation exercises depending on particular weather phenomena to be present that archived data have to be used, this is as close as it gets to real operations in the context of such an operational validation. Moreover, an adapted version of METForTAM service tailored for Bratislava Airport was included and validated in EXE-PJ.04-02 V2.06 [46] as well.

The METForTAM service has been designed as having 6 messages that can be individually subscribed to. Five of these messages contain the standard parameters and the sixth message on local phenomena is supposed to be a kind of wild card message that leave an open space for particular needs of airports. As an example for such local information, data elements describing the Bora phenomenon have been included in the service. Since, this is completely new work it has not the same TRL as the METForTAM service, it is necessary to take note of the fact that this is just exemplary and therefore not to be included in the assessment of the TRL, since it is the nature of this service to have an open structure with respect to local phenomena that can never be assessed in its entirety. Only the five standard messages should be regarded as under TRL6 scrutiny. Therefore, separate exercises have been conducted to demonstrate the MET capability to detect Bora wind and to classify Bora wind events. Both these exercises have TRL 4 only.

In dependency with requirements derived for enhancing separation procedures, a glideslope wind profile product is newly developed. Although the MET product is new, mature sources like Radar and Lidar sensors have been used. Therefore, the payload itself is declared as TRL 6 whereas the corresponding METForWTS service for which this capability, although not exclusively, has been developed will reach only TRL 2. METForWTS is fully modelled in MEGA and a preliminary SDD are provided that may be subject to change in wave 2 (solution 14).

The new component of the GWMS (Ground Weather Management System) prototype that implements the METGate functional block for the Aerodrome ATM MET CC (the “local METGate”) as the payload tailoring component that has the right bindings to provide local MET services on Yellow and Purple Profile (Blue Profile is deemed not applicable for MET services), developed in the task “GWMS Enhancement”will reach TRL 6.

With regard to activities related to the DLR Cb-global capability and at the Cb-global yellow profile service, previous work was performed within the EU FP6 project “FLYSAFE” (Airborne integrated systems for safety improvement, flight hazard protection and all weather operations, 2005-2009, http://cordis.europa.eu/projects/rcn/75794_en.html) and within DLR internal research projects. During these projects, both the Cb-global capability and the Cb-global yellow profile service have been intensively tested in cooperation with aviation stakeholders in several campaigns, e.g. at airports and in data link tests. Based on the feedback of the aviation stakeholders, the technologies have been further developed and had already reached TRL5 before the start of SESAR 2020. Within SESAR2020 PJ18-04b both the Cb global capability and the Cb-global yellow profile service have been brought to TRL6. For Cb-global capability this means that within SESAR2020 the detection and nowcasting of thunderstorm hazards has been optimized and also extended to the detection and nowcasting of high altitude icing conditions (HAIC) and convectively induced turbulence (CIT) in order to enable flight safety and fuel efficiency. For the Cb-global yellow profile service this means that the performance of the provision of the Cb-global data to an interface where the data are picked up by service provider for up and downlink has been optimized with regard to data formats, transmission times, and communication handling.

About activities related to environmental impact, previous work on the subject was covered in the SESAR Exploratory Research Project ATM4E “Air Traffic Management for Environment” which explored the feasibility of a concept for environmental assessment of ATM operations working towards environmental optimisation of air traffic operations in the European airspace. The concept developed relied on the usage of the MET interface in order to pass on information relating to climate impact of aviation emissions. Such information is required during the flight planning process as a requisite for enabling an environmental performance assessment during trajectory optimisation, as proposed within Wave 1 Exploratory Research project (2016-2018). From this overall concept, PJ18-04b reuses the approach on how to establish an interface between air traffic management and the environmental and climate impact of aircraft operations. Hence, within PJ18-04b, the same approach is applied by using the MET interface for providing information, which is relevant for environmental performance of operations.

2.4 Structure of the document

Chapter ¡Error! No se encuentra el origen de la referencia. provides a summary of the key information and elements contained in the document.

Chapter ¡Error! No se encuentra el origen de la referencia. informs on the purpose of the document, the intended audience, structure of the document and explains the abbreviations and acronyms used throughout the document.

Chapter ¡Error! No se encuentra el origen de la referencia. describes the general background for the technical validation report for TRL6, provides a summary of the validation plan.

Chapter ¡Error! No se encuentra el origen de la referencia. presents a summary of the technical validation results including analysis of validation results per validation objective.

Chapter ¡Error! No se encuentra el origen de la referencia. presents the conclusions and recommendations.

Chapter ¡Error! No se encuentra el origen de la referencia. lists the applicable reference documents

The technical validation exercises are further detailed in individual appendix.

2.5 Glossary of terms

Term	Definition	Source of the definition
4DWxCube	Gathers and consolidates ATM relevant meteorological (MET) information from various sensors and MET information providers. In turn, the 4DWxCube DS provides access services that allow ATM actors to access the consolidated MET information in contextually sensitive packages. It also provides local Aerodrome relevant MET warnings and feedback of consolidated MET information to forecasting models as specialized interfaces. PJ.18-04b view: Ground Weather Management System (GWMS) is realising the "local" 4DWxCube instanced in the Aerodrome ATM-MET_CC. It concentrates mainly on local acquisition of MET data but includes as well information obtained from ATM-MET_CC. A new consolidation FB is introduced: C06 "Local MET Information", because some locally obtained MET data (e.g. Radar and Lidar wind data) need consolidation in terms of provision of combined wind shear alerts. Outcome are services mainly for stakeholders in the Airport_CC. SWIM YP and PP will be used.	EATM Portal
AIR-REPORT	A report from an aircraft in flight prepared in conformity with requirements for position, and operational and/or meteorological reporting.	ICAO Annex 3[63]
Cb-global	Hazard detection and nowcasting (=forecasting up to one hour) related to active thunderstorms (Cb), convective induced turbulence (CIT), and high altitude ice crystals (HAIC) based on satellite data.	DLR[56][57]**¡Error! No se encuentra el origen de la referencia.**

	Cb-global is the extended version of the former Cb-TRAM[55][57].	
Cb	Thunderstorm	MET community
CCF	Climate change functions, providing a quantitative estimate of climate impact associated with aviation emissions, as established within ATM4E (Exploratory Research).	DLR[67][68]
CIT	Convective induced turbulence	MET community
Computed Current RWYCC	Current RWYCC estimate provided by the RCAMS system to be verified by the Airport Operator	PJ.03b-06 OSED [42]
Computed Predicted RWYCC	Prediction of RWYCC varioation over a short time period in the future provided to Airport Operator by RCAMS system.	PJ.03b-06 OSED [42]
HAIC	High altitude icing conditions	MET community

Table 1: Glossary of terms

2.6 Acronyms and Terminology

Term	Definition
ADD	Architecture Definition Document
AN	Availability Note
ANSP	Air Navigation Service Provider
API	Application Program Interface
APOC	Airport Operations Centre
ATM	Air Traffic Management
AWOS	Automated Weather Observing System
CC	Common Component
DS	Data Set
E-ATMS	European Air Traffic Management System
EFB	Electronic Flight Bag
E-OCVM	European Operational Concept Validation Methodology
GRF	Global Reporting Format

GWMS	Ground Weather Management System
IBP	Industry Based Platform
ICAO	International Civil Aviation Organization
IR	Infrared
IRS	Interface Requirements Specification
INTEROP	Interoperability Requirements
IS	Information Service
MET	Meteorology, Meteorological
OFA	Operational Focus Areas
OSED	Operational Service and Environment Definition
PP	Purple Profile
PPI	Plan Position Indicator
RCAMS	Runway Surface Condition computing system
RCR	Runway Condition Report
RHI	Range Height Indicator
RVR	Runway Visual Range
RWYCC	Runway Condition Code
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SOA	Service Oriented Architecture
SPR	Safety and Performance Requirements
SUT	System Under Test
SWIM	System Wide information Management
TAM	Total Airport Management
TRL	Technical Readiness Level
TS	Technical Specification
TVALP	Technical Validation Plan
TVALR	Technical Validation Report
VALP	Validation Plan
VALR	Validation Report

VALS	Validation Strategy
VIS	Visible
WTS	Wake Turbulence Separation
YP	Yellow Profile

Table 2: Acronyms and terminology

3 Context of the Technical Validation

This chapter describes the context of the technical validation. It provides a summary of the developed components, the proposed solutions, the validation plan and validation exercises.

3.1 PJ.18-04b: a summary

PJ.18-04b MET Information in 4D Trajectory Management: Developments in new or enhanced meteorological (MET) information will improve the quality, consistency and usability of the information in a full 4D trajectory flight. PJ.18-04b develops information services and capabilities based on operational requirements in order to realise the improvements.

PJ.18-04b has performed a range of activities spread in domains addressing system capabilities (CC) and information services (IS). The domains consolidate developments with a specific (MET) purpose and can contain developments of several MET products with different maturity levels. **The domains were only meant to better structure the activities and facilitate collaboration between partners.**

Validation exercises were performed on the basis of each components (i.e. capability or information service). **The maturity of the solutions or activities should be therefore considered per (group) of components, not per domain**.

Here below a description of each domain addressed by PJ.18-04b with associated components is provided.

CC.2.2 "GWMS Enhancement": GWMS is prototype implementing a local instance of the 4DWxCube developed by WP11 [52] and WP15 [54] in SESAR 1 (part of Solution #21). In SESAR 2020, the activity aims to enhance the GWMS prototype making it 'SWIM' compatible for all its output (i.e. developing and implementing the MET-GATE FB for the local instance of 4DWxCube) which therefore has crosslinks to new MET service developments e.g. like METForTAM and METForWTS, since MET services developed in SESAR1 did not cover the information that GWMS provided to APOC in EXE669 of OFA05.01.01. Requirements for the "local MET-GATE" have been collected and consolidated from those requirements of WP11 and WP15, which have not been validated before and are still <in progess>. These serve as the baseline for this "enhancement activity" that will effectively validate the FB "MET-GATE" in the Aerodrome ATM MET CC. Although it can be considered a validation of the larger scope of GWMS, the swapping of product providers while maintaining service provision that has been validated in this solution, does have a clear link to this activity, since it involves the whole processing chain from source to service.

CC.3.1 "**Airport MET Information and Alert Generation Enhancement":** focuses on MET information specifically affecting the airport and surrounding area in the short term by improving observations (including remote sensing) as well as forecasts. The information (about phenomena) will be used such that it will enable the generation of alerts better. Specifically, it will concentrate on short term, high resolution observation and nowcasting products, both deterministic and probabilistic, serving ATM needs.

Phenomena detection relevant for ATM operational processes is the driving force for the development of MET capabilities (as an example describing special wind regimes for affected airports e.g. BORA).

Phenomena are a further algorithmic abstraction from the pure MET information. Therefore, most of this activity will deal with development of such algorithms.

CC.4.2 "Enhanced Airport (surface based and remote sensing) MET Observations" deals with pure MET capabilities for ATM relevant phenomena. Based on evolved information exchange requirements it is anticipated that new MET capabilities will have to be developed. For new local sensors, integration with regional information and development of appropriate algorithms will be needed.

Sensors subsumed under the Enhanced MET Sensor TS (SESAR1 Architecture) need to be consolidated among themselves as well as with data measured by the Standard MET Sensors TS and additional information coming from outside the airport (e.g. aircraft based observations during approach). In SESAR 1 the focus was on providing all products from the different data sources that satisfy the requirements. Therefore, consolidation and harmonisation as a core capability for local applications will be required.

IS.1 "MET Information Services to support High Performing Airport Operations": Based on the Information Exchanged Requirements dedicated MET SWIM services tailoring results from CC.3.1 and CC.4.2 to specific operational working areas will be developed to support operational solutions in their context.

The PJ18-04b subtasks "18-04b.CC.2.3 – Cockpit Ready MET" and "18-04b.CC.3.3 – MET Information Generation for Climate-optimised routing" aim at developing prototypes for the generation of advanced MET information tailored to the needs of both, the use in the cockpit regarding route adjustments (prototype called "Cb-global") and the use at the ground regarding the strategic flight planning. Both prototypes are validated within PJ18-04b in two independent validation exercises performed by DLR at DLR premises. An additional third validation exercise will be performed by DLR for the development of a data provision service within subtask "18-04b.IS.5 - MET Information Services for aircraft information and aircraft control domain". This service serves Cb-global data to a yellow profile interface where the data are picked up by the partners from PJ18-04c for their PJ18-04c validation exercises.

All Met data provided by the DLR prototypes is related to weather hazards and is to be considered as additional, but NOT mandatory information according to ICAO Annex 3 [63].

CC.2.3. 'Cockpit Ready MET' focuses on MET information about weather hazards like thunderstorm cells en-route generated by the prototype "Cb-global". The MET info comprises analyses of the weather hazard as well as nowcasts (=forecasts up to one hour based on the observation). It will be provided in a format that is suitable for real time up-link into cockpit EFBs, in accordance with the requirements from PJ.18-04c [49]. Cb-global is able to detect and nowcast thunderstorms (Cb), convectively induced turbulence (CIT), and high altitude ice-crystals (HAIC). The validation exercise for the Cb-global prototype will proof that Cb-global information is able to detect and nowcast Cb, HAIC, and CIT and considerably contributes to flight safety and fuel savings, if this information would be used in the cockpit for the planning and adjustment of flight routes.

CC.3.3 'MET Information Generation for Climate-optimised routing' focuses on the development of an advanced MET service which enables identification of climate-optimized trajectories by provision of spatial and temporal information on induced climate change, described as climate change functions (i.e. climate impact per aviation emission). This task on contrail formation represents an intermediate step towards a full climate impact assessment. The MET information generated within this task provides information on those areas, e.g. along the flight trajectory, where contrails can form. However, it does not yet provide a quantitative information on how large the climate impact is, e.g. by indicating an average temperature change induced. However, for the time being, such climate impact information relies on physical climate impact metrics, providing a quantitative information on climate change induced by a contrail formed, hence having a lower TRL so far. Within the context of this task the MET information provided relates to of contrails which can be calculated from meteorological conditions with physical principles being published in [71]. During the flight planning process such meteorological conditions can be derived from MET forecast data [67] in order to identify on those areas where contrails can form [68], hence targeting TRL4. Stakeholder needs and expectations have been discussed and documented in ATM4E [67], which will determine user acceptability when targeting TRL4.

IS.5 'MET Information Services for aircraft information domain' focuses on the development of a service providing MET hazard information generated by Cb-global to an Airspace User Operations Centre or a provider of up and downlink technologies to and from the cockpit of aircraft (e.g. up and donwlink in cockpit EFBs). The resulting prototype is called "Cb-global service". The validation exercise will prove that the Cb-global service is able to regularly provide Cb-global data to a yellow profile interface in a SWIM compatible standard format in real time.

SESAR Technological Solution ID	**SESAR Technological Solution Description**	**Master or Contributing (M or C)**	**Contribution to the SESAR Technological Solution short description**	**Enablers ref. (from EATMA)**
PJ.18-04b Improved MET Information	Solution PJ.18-04b, Improved MET information is there for every Solution in the SESAR2020 Industrial Research (IR) Programme that has Meteorological Information (MET) need, which requires component (prototype) development	M	Providing local MET services via SWIM	DS18: METEO-03c, METEO-04c, METEO-05c, METEO-06c METEO-07c [CR02983], METEO-08c [CR02971], SWIM-APS-06b[2] DS19 new: METEO-10a [CR02978] METEO-10b [CR02980] METEO-11a [CR02981]

[2] A change request will be created to link this EN with PJ.18-04b in DS19.

SESAR Technological Solution ID	SESAR Technological Solution Description	Master or Contributing (M or C)	Contribution to the SESAR Technological Solution short description	Enablers ref. (from EATMA)
				METEO-11b [CR02982] METEO-12a [CR03019] METEO-12b [CR03022] SVC-037 [CR02985] SVC-040 [CR02986] HUM-020 [CR02984] SENA01233 [CR]
		M	Enhanced Airport (surface based and remote sensing) MET observations	METEO-10a METEO-10b METEO-11a METEO-11b
		C	MET Observer role	HUM-020

Table 3: SESAR Technological Solution(s) under Validation

From all activities, PJ.18-04b proposes two solutions that are considered mature for implementation with the corresponding ENs:

- Solution 1: GWMS capability linked with Glide Wind Profile capability and METForTAM service. The applicable ENs are (see also TS [39] chapter 3.2):
    - EN from Sesar 1: METEO-03c, METEO-04c, METEO-07c (CR for DS20 pending), METEO-08c (CR for DS20 pending), SWIM-APS-06b
    - Endorsed for DS18: METEO-10a, METEO-10b, METEO-11a (CR for DS20 pending), METEO-11b, METEO-12a, METEO-12b, SVC-037, SVC-040
    - CR for DS20: SENA01221, SENA01222, SENA01223, SENA01224, SENA01225, SENA01226, SENA01227, SENA01228, SENA01229, SENA01230, SENA01233, SENA01237,

- Solution 2: Cb-global capability linked with Cb-global service. The applicable ENs are:METEO 5c, METEO 6c, and SENA01233 (CR).

3.2 Summary of the Technical Validation Plan

3.2.1 Validation Plan Purpose

The key PJ.18-04b technical validation objective is to validate that the developed components are fit for purpose in view of their incorporation in various ATM systems, serving the ATM operational objectives expressed by the Operational Solutions.

According to the planned activities, the following high-level objectives are established:

- Evaluate MET information need by ATM Solutions;
- Provide appropriate MET information service to meet ATM Solutions' validation objectives, and

Technical validation is considered to validate the Technical Solution on its operational usability in terms of providing the users (represented in an operational validation exercise) an indication of the confidence they will be able to place in the served information. Technical validation is conducted after verification, which is limited to verifying prototypes and provided information services against the stated requirements.

3.2.2 Summary of Technical Validation Objectives and success criteria

The table below provides a summary of all main validation objectives based on TS requirements of different domains. The success criteria can be consulted in the PJ.18-04b TVALP [40] and in Table 5 of Chapter 4. They are not repeated here due to the large number. The results documented in the Appendixes also reflect the assessment of the success criteria.

Identifier	Objective	Title	Category	Key environment conditions	TRL Phase
OBJ-18-04b-TRL6-TVALP-001	To validate that the GWMS as local 4DWxCube fulfils general SWIM functionalities and settings required to provide and receive SWIM services.	4DWxCube general SWIM functionalities	Technical feasibility	Nominal and adverse weather conditions	TRL 6
OBJ-18-04b-TRL6-TVALP-002	To validate that the GWMS provides reliable subscription management functionalities.	MET SWIM service subscription management	Technical feasibility	Nominal and adverse weather conditions	TRL 6
OBJ-18-04b-TRL6-TVALP-003	To validate that the GWMS provides different service payloads.	MET SWIM service payload management	Technical feasibility	Nominal and adverse weather conditions	TRL 6

Identifier	Objective	Title	Category	Key environment conditions	TRL Phase
OBJ-18-04b-TRL6-TVALP-004	To validate that the GWMS is able to provide a PP SWIM service correctly.	MET PP SWIM service design	Technical feasibility	Nominal weather conditions	TRL 6
OBJ-18-04b-TRL6-TVALP-005	To validate that the GWMS is able to receive A/C MET observations as PP SWIM service downlink correctly and use them for winds aloft products.	MET PP SWIM service design	Technical feasibility	Nominal weather conditions	TRL 6
OBJ-18-04b-TRL4-TVALP-006	To validate that dangerous runway crosswinds (Bora wind) and phenomena associated with Bora in the vicinity of Dubrovnik airport can be observed by Doppler Wind Lidar.	Bora Wind Measurement	Technical feasibility	Adverse wind conditions	TRL 4
OBJ-18-04b-TRL4-TVALP-007	To validate that dangerous wind variations (wind shear) in Bora wind in the vicinity of Dubrovnik airport can be observed by Doppler Wind Lidar	Bora Wind Shear Measurement	Technical feasibility	Adverse wind conditions	TRL 4
OBJ-18-04b-TRL4-TVALP-008	To validate that the Bora wind classification algorithm can be run on measurements derived from available MET infrastructure and provide correct classification results.	Bora Wind Classification Algorithm	Technical Feasibility	Adverse wind conditions	TRL 4
OBJ-18-04b-TRL6-TVALP-009	To validate that a reliable wind profile of head- and crosswind components can be derived from Doppler Lidar or Doppler Weather Radar measurements.	Glideslope wind profile	Technical feasibility	Hub Airport with complex layout, small airport	TRL 6
OBJ-18-04b-TRL2-TVALP-010	To validate that the payload of the glide slope wind profile	Glideslope wind profile service	Concept Validity	Hub Airport with complex layout, small airport	TRL 2

Identifier	Objective	Title	Category	Key environment conditions	TRL Phase
	service (METForWTS) has been correctly designed.				
OBJ-18-04b-TRL4-TVALP-012	To validate that the Runway Weather Monitoring and Forecast Service (input)-RWYWeather is capable of providing all the required data (with SWIM dissemination functionality) for RCAMS system (AWOS, ground sensor, etc.)	Runway Weather Monitoring and Forecast Service (input) provision - RWYweather	Technical feasibility	Nominal and adverse weather conditions	TRL 4
OBJ-18-04b-TRL4-TVALP-013	To validate that the Runway Weather Monitoring and Forecast Service (output) is able to disseminate RCR as well as any additional information generated by RCAMS system (especially short term runway condition forecasts).	Runway Weather Monitoring and Forecast Service (output) provision	Technical feasibility	Nominal and adverse weather conditions	TRL 4
OBJ-18-04b-TRL4-TVALP-014	To validate that the Remote Tower MET Service is correctly being provided.	Remote Tower MET Service provision	Technical feasibility	Nominal and adverse weather conditions	TRL 4
OBJ-18-04b-TRL6-TVALP-011	To validate that the local 4DWxCube is able to switch MET product providers.	Switch of MET Product provider	Technical feasibility	Nominal and adverse weather conditions	TRL 6
OBJ-18-04b-TRL4-TVALP-015	To validate that visible light/IR camera can provide valuable inputs to detection of cloud/ visibility/phenomena at an Airport	Airport MET Camera Imagery	Technical feasibility	Small airports, various weather conditions	TRL 4
OBJ-18-04b-TRL6-TVALP-016	To show that the availability of the detection and nowcasting of Cb, CIT, and HAIC information from Cb-global in the cockpit contributes to flight safety	Cb-global contributes to flight safety	safety	En route adverse weather conditions related to Cb	TRL 6

Identifier	Objective	Title	Category	Key environment conditions	TRL Phase
OBJ-18-04b-TRL6-TVALP-017	To show that the use of the detection and nowcasting of Cb, CIT, and HAIC information from Cb-global contributes to fuel savings	Cb-global contributes to fuel efficiency	Performance and safety	En route adverse weather conditions related to Cb	TRL 6
OBJ-18-04b-TRL4-TVALP-018	To show that areas along the trajectory where (persistent) contrails are formed can be identified by "Contrail formation" MET information	Contrail formation	Technical feasibility	En route nominal weather conditions	TRL 4
OBJ-18-04b-TRL6-TVALP-019	To build a service that delivers Met hazard information via a yellow profile to an Aircraft and Flight Specific Met Integration System	Cb-global yellow profile service	Technical feasibility	En route adverse weather conditions related to Cb	TRL 6

Table 4: Overview of technical validation objectives

3.2.3 Technical Validation Assumptions

No specific assumptions were defined for the technical validation exercises.

3.2.4 Technical Validation Exercises List

This section provides details about technical validation exercises that are performed by PJ.18-04b. Most of the exercises have as validation technique "Laboratory Test" since it will not be integrated and used in any other external platform and exercise. The content (MET product) itself has reached TRL 6 level, but since the actual transfer of message as service will be not tested, Laboratory test was assigned.

[EXE]

Identifier	EXE-18-04b-TRL6-001_LDO
Title	Glideslope wind profile
Description	To validate that an enhanced glideslope wind profile capability can be provided using one scanning Doppler Lidar and/or Radar.
Expected achievements	Supporting MET Information for arrival and departure sequence
TRL	<TRL6>
T. Validation Technique	<Laboratory Test>
Start Date	01/04/2019

End Date	30/06/2019
T. Validation Coordinator	Leonardo Germany GmbH
T. Validation Platform	Leonardo IBP GWMS
T. Validation Location	Neuss, Leonardo Premises
Status	Validated
Dependencies	None

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<V&V Objective>	OBJ-18-04b-TRL6-TVALP-009

[EXE]

Identifier	EXE-18-04b-TRL2-002_LDO
Title	METForWTS
Description	To validate that the payload of the METForWTS service which is to be implemented in the local 4DWxCube has been correctly designed
Expected achievements	Supporting MET Information for arrival and departure sequence
TRL	<TRL2>
T. Validation Technique	<Review of design>
Start Date	01/04/2019
End Date	30/06/2019
T. Validation Coordinator	Leonardo Germany GmbH
T. Validation Platform	Leonardo IBP GWMS
T. Validation Location	Neuss, Leonardo Premises
Status	Validated
Dependencies	None

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b

<V&V Objective>	OBJ-18-04b-TRL2-TVALP-010

[EXE]

Identifier	EXE-18-04b-TRL4-001_CCL
Title	Bora wind detection
Description	To validate that a Scanning Doppler Lidar is a suitable instrument to detect and classify Bora wind hazards
Expected achievements	Technical feasibility, support of ATC and Pilots
TRL	<TRL4>
T. Validation Technique	<Analysis of Measurement Campaign>
Start Date	07/11/2018
End Date	31/03/2019
T. Validation Coordinator	Croatia Control
T. Validation Platform	Measurement data from Dubrovnik campaign performed in PJ04-02
T. Validation Location	LDO Germany Neuss, Croatia Control Zagreb
Status	Validated
Dependencies	PJ.04-02, VAL EXE PJ.04.02-V2.04

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<V&V Objective>	OBJ-18-04b-TRL4-TVALP-006
<V&V Objective>	OBJ-18-04b-TRL4-TVALP-007

[EXE]

Identifier	EXE-18-04b-TRL4-002_CCL
Title	Bora wind classification algorithm
Description	To validate that the Bora wind classification algorithm provides correct results.
Expected achievements	Technical feasibility
TRL	<TRL4>

T. Validation Technique	<Laboratory Test>
Start Date	01/03/2019
End Date	31/05/2019
T. Validation Coordinator	Croatia Control
T. Validation Platform	LDO Germany premises, CCL premise
T. Validation Location	LDO Germany, Neuss; CCL premise, Zagreb
Status	Validated
Dependencies	PJ.04-02, VAL EXE PJ.04.02-V2.04

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<V&V Objective>	OBJ-18-04b-TRL4-TVALP-008

[EXE]

Identifier	EXE-18-04b-TRL6-004_LDO
Title	GWMS SWIM Enhancement
Description	To validate that the GWMS provides SWIM PP service
Expected achievements	Technical feasibility
TRL	<TRL6>
T. Validation Technique	<Gaming Exercise, Laboratory Test>
Start Date	01/04/2019
End Date	30/06/2019
T. Validation Coordinator	Leonardo Germany GmbH + Leonardo Italy SPA
T. Validation Platform	Leonardo IBP GWMS
T. Validation Location	Leonardo premise, Germany + Italy
Status	Validated
Dependencies	No

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<V&V Objective>	OBJ-18-04b-TRL6-TVALP-001
<V&V Objective>	OBJ-18-04b-TRL6-TVALP-002
<V&V Objective>	OBJ-18-04b-TRL6-TVALP-003
<V&V Objective>	OBJ-18-04b-TRL6-TVALP-004
<V&V Objective>	OBJ-18-04b-TRL6-TVALP-005

[EXE]

Identifier	EXE-18-04b-TRL6-005_LDO
Title	GWMS: Swapping MET providers
Description	To validate that the GWMS is able to change the source of MET products.
Expected achievements	Technical feasibility
TRL	<TRL6>
T. Validation Technique	<Laboratory Test>
Start Date	01/04/2019
End Date	30/06/2019
T. Validation Coordinator	Leonardo Germany GmbH
T. Validation Platform	Leonardo IBP GWMS
T. Validation Location	Leonardo premise, Germany
Status	Validated
Dependencies	No

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<V&V Objective>	OBJ-18-04b-TRL6-TVALP-011

[EXE]

Identifier	EXE-18-04b-TRL4-001_LPS SR

Title	Remote Tower MET Service
Description	To validate that Remote Tower MET Service is correctly provided.
Expected achievements	Technical feasibility
TRL	<TRL4>
T. Validation Technique	<Laboratory testing>
Start Date	01/04/2019
End Date	30/06/2019
T. Validation Coordinator	LPS SR (B4)/MicroStep-MIS
T. Validation Platform	Poprad Airport / Bratislava Remote MET Observer
T. Validation Location	Bratislava, MicroStep-MIS premises
Status	Validated
Dependencies	PJ.05-05

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<V&V Objective>	OBJ-18-04b-TRL4-TVALP-014

[EXE]

Identifier	EXE-18-04b-TRL4-002_LPS SR
Title	Runway Weather Monitoring and Forecast Services (input/output)
Description	To validate that Runway Weather Monitoring and Forecast Services (input/output) is correctly provided
Expected achievements	Technical feasibility
TRL	TRL4
T. Validation Technique	<Laboratory testing>
Start Date	01/04/2019
End Date	30/06/2019
T. Validation Coordinator	LPS SR (B4)/MicroStep-MIS
T. Validation Platform	ARWIS
T. Validation Location	Bratislava, MicroStep-MIS premises

Status	Validated
Dependencies	PJ.03b-06

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<V&V Objective>	OBJ-18-04b-TRL4-TVALP-012
<V&V Objective>	OBJ-18-04b-TRL4-TVALP-013

[EXE]

Identifier	PJ.05-05 EXE
Title	Airport MET Camera
Description	To validate that the Airport MET Camera can be used to provide reliable input to determination of cloud/visibility/MET phenomena
Expected achievements	Technical feasibility
TRL	<TRL4>
T. Validation Technique	<Field test>
Start Date	01/06/2018
End Date	31/07/2018
T. Validation Coordinator	LPS SR (B4)/Microstep-MIS
T. Validation Platform	Poprad Airport / Bratislava Remote MET Observer (IR/VIS camera and other supporting MET sensors are installed at Poprad airport as well as a local server gathering and storing primary data)
T. Validation Location	Poprad airport
Status	<validated>
Dependencies	PJ.05-05

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<V&V Objective>	OBJ-18-04b.CC4.2-TRL4-TVALP-015

[EXE]

Identifier	EXE-PJ18-04b-TRL6-001_DLR
Title	Cb-global capabilities
Description	Cb-global will be run for a number of historical thunderstorm cases. The detection and nowcasting of Cb-global will then be compared to independent observations. The MET situation during aircraft accidents and incidents will be analysed with Cb-global in order to show Cb-global's capability to increase flight safety. In addition, real flown flight routes will be compared with flight routes optimized on the basis of Cb-global information in order to calculate fuel savings.
Expected Achievements	Cb-global's capability with regard to flight safety and fuel savings is proven
TRL	TRL6
T. Validation Technique	Application of Cb-global on many use cases
Start Date	01/04/2019
End Date	30/06/2019
Validation Coordinator	DLR/AT-ONE
Validation Platform	DLR
Validation Location	DLR Oberpfaffenhofen
Status	Validated
Dependencies	none

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<Validation Objective>	OBJ-18-04b-TRL6-TVALP-016
<Validation Objective>	OBJ-18-04b-TRL6-TVALP-017

[EXE]

Identifier	EXE-18-04b-TRL6-002_DLR
Title	Cb-global yellow profile service

Description	Cb-global information is transferred via a secured interface to a provider of up- and downlink services
Expected Achievements	The transfer of Cb-global information via the secured interface is feasible within a reasonable time period
TRL	TRL6
T. Validation Technique	Real time emulation
Start Date	01/04/2019
End Date	30/06/2019
Validation Coordinator	DLR/AT-ONE
Validation Platform	DLR
Validation Location	DLR Oberpfaffenhofen
Status	Validated
Dependencies	none

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ18-04b
<Validation Objective>	OBJ-18-04b-TRL6-TVALP-019

[EXE]

Identifier	EXE-PJ18-04b-TRL4-003_DLR
Title	Contrail formation (by algorithm)
Description	On the basis of reanalysis and observational data it will be verified that regions of contrail formation can be identified with Contrail formation data.
Expected Achievements	Identification of contrail formation regions is feasible with Contrail formation (algorithm).
TRL	TRL4
T. Validation Technique	<Laboratory testing>
Start Date	Q4/2018
End Date	Q4/2019
Validation Coordinator	DLR (AT-ONE)

Validation Platform	DLR
Validation Location	DLR (AT-ONE) Oberpfaffenhofen
Status	Validated
Dependencies	none

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	PJ.18-04b
<Validation Objective>	OBJ-18-04b-TRL4-TVALP-018

3.3 Deviations

3.3.1 Deviations with respect to the SJU Project Handbook

There is no deviation as already indicated in the TVALP.

3.3.2 Deviations with respect to the Technical Validation Plan

There is no deviation with respect to the Validation exercises described in the TVALP. Minor deviations (within the exercise, e.g. data availability, etc.) are described in the appendices.

4 SESAR Technological Solution PJ18.04b Validation Results

4.1 Summary of SESAR Technological Solution PJ.18-04b Validation Results

This section presents the summary of the technical validation results.

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.001	It is possible to provide MET Information as SWIM services to stakeholders.	Yellow and Purple Profile Services are successfully provided to consumers.	OK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.002	It is possible to accommodate new SWIM services without major redesign of the GWMS.	New services are developed, integrated and delivered.	OK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.003	The GWMS is able to support 10000 subscriptions simultaneously.	By design, this is just a matter of hardware used and the job of the SWIM TI	N/A
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.004	The GWMS authentication by users is done between SWIM nodes.	The authentication is done with a SWIM node.	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.005	The GWMS does allow the configuration of SSL-based transport protocol (AMQPS) for metadata and data transfer to maintain data security.	SSL has been successfully used	OK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.006	The GWMS is designed according to Service-oriented architecture (SOA) principles.	Design check confirm SOA principles.	OK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.007	The GWMS allows issuing alerts to indicate that parts or all of the MET Information of a service is not available, out of date or cannot be generated.	In principle possible, but no SWIM service is designed, yet, that allows for this feature. Generation of such information is done by GWMS and has been tested in EXE669 in SESAR1, but not explicitly here.	NOK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.008	The GWMS delivers MET Services to local ATM consumers	Not included and tested in any exercise	NOK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
			within a maximum delivery time depending on the MET product.		
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.009	The GWMS delivers MET Services to local ATM consumers using either SWIM Yellow or Purple Profile.	Yellow and Purple Profile Services are successfully provided to consumers.	OK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.010	The GWMS provides services compliant with the latest releases of SESAR AIRM and ISRM except when duly justified.	Not a technical requirement, but one of service design	OK
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.001	The GWMS notifies users if a MET product within a service is not available.	No notification, but empty data tags are delivered if information has not been provided. Could be part of a service interface, because such information is available	NOK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.002	The GWMS always includes the latest available product.	Required as per system design, because processing is triggered by new data being available	OK
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.003	The GWMS provides an API to allow users to specify their requests.	Outdated formulation. The “API” is the collection of service interfaces. Through these users can specify their subscriptions/requests in the restricted manner allowed by the interface design done via SWIM node.	N/A
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.004	The GWMS provides an API to allow users to specify their subscription profiles.	Not clear what a subscription profile should be as the whole point of the SWIM TI is to decouple provider and consumer in space and time. Requirement should be deleted.	N/A
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.005	The GWMS provides a message if a subscription is valid or not.	Part of subscription management done by the SWIM node. Out of scope.	N/A

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.006	The GWMS negotiates communication with the SWIM infrastructure (node) only using a certificate.	Tested	OK
OBJ-18-04b-TRL6-TVALP-003	MET SWIM service payload management	CRT-18-04b-TRL6-TVALP-003.001	The GWMS provides complex services in addition to standard services.	GWMS is extended and provides customized services in addition to ICAO related services like e.g. METAR.	OK
OBJ-18-04b-TRL6-TVALP-004	MET PP SWIM service design	CRT-18-04b-TRL6-TVALP-004.001	GWMS (specific instance at an airport) receives request for METAR service (adapted to AMQPS 1.0) by an A/C application using routing of the request based on ICAO code of the airport. GWMS replies message with meta data in such a way that it is	Exercise was completed as detailed on the left.	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
			routed to the right requestor.		
OBJ-18-04b-TRL6-TVALP-004	MET PP SWIM service design	CRT-18-04b-TRL6-TVALP-004.002	GWMS (specific instance at an airport) receives subscription for METAR service (adapted to AMQPS 1.0) by an A/C application using routing of the subscription request based on ICAO code of the airport. GWMS publishes the payload with meta data in such a way that it is routed to the right subscriber.	Exercise was completed as detailed on the left.	OK
OBJ-18-04b-TRL6-TVALP-005	MET PP SWIM service design	CRT-18-04b-TRL6-TVALP-005.001	GWMS is sending correct subscription messages that are accepted by the SWIM	Exercise was completed as detailed on the left.	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
			PP ground node.		
OBJ-18-04b-TRL6-TVALP-005	MET PP SWIM service design	CRT-18-04b-TRL6-TVALP-005.002	A/C MET observations subscribed and filtered using the right filter criteria are received correctly by GWMS.	Exercise was completed as detailed on the left.	OK
OBJ-18-04b-TRL6-TVALP-005	MET PP SWIM service design	CRT-18-04b-TRL6-TVALP-005.003	GWMS is sending correct unsubscription messages that are accepted by the SWIM PP ground node and lead to unsubscription of previously subscribed messages.	Exercise was completed as detailed on the left.	OK
OBJ-18-04b-TRL4-TVALP-006	Bora Wind Measurement	CRT-18-04b-TRL4-TVALP-006.001	Lidar data confirms north-east wind (runway crosswind) at lowest levels and approach area.	Average result of 4.88/5 clearly showed that validation participants strongly agree that lidar data would be useful for determining prevalence of wind speed and direction,	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
				not only on runway, but also in vicinity of Dubrovnik airport.	
OBJ-18-04b-TRL4-TVALP-006	Bora Wind Measurement	CRT-18-04b-TRL4-TVALP-006.002	Height of Bora wind layer can be detected from Lidar images.	Average result of 4.31/5 showed that validation participants agree that, in most cases, lidar RHI images could be beneficial in determining height of Bora layer, i.e. height of layer in which Bora wind is strong and prevalent.	OK
OBJ-18-04b-TRL4-TVALP-006	Bora Wind Measurement	CRT-18-04b-TRL4-TVALP-006.003	Heterogeneous wind flows, which could represent turbulent areas, can be detected from Lidar images.	Average result of 4.31/5 indicate that validation participants agree with given hypothesis that lidar data would be useful for detecting turbulent areas in vicinity of Dubrovnik airport.	OK
OBJ-18-04b-TRL4-TVALP-007	Bora Wind Shear Measurement	CRT-18-04b-TRL4-TVALP-007.001	Wind shear in approach to the Dubrovnik airport can be detected from lidar images.	Average result of 4.63/5 indicate that validation participants strongly agree with given hypothesis that lidar data would be useful for detecting areas	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
				affected by strong wind shear in approach to Dubrovnik airport.	
OBJ-18-04b-TRL4-TVALP-007	Bora Wind Shear Measurement	CRT-18-04b-TRL4-TVALP-007.002	Wind rotors and wind shear in vicinity of Dubrovnik airport can be detected from lidar RHI (vertical) and PPI (horizontal) images.	Average result of 4.25/5 indicate that validation participants agree with given hypothesis that lidar data would be useful for detecting areas affected by strong wind shear and vertical wind rotors in vicinity of Dubrovnik airport.	OK
OBJ-18-04b-TRL4-TVALP-008	Bora Wind Classification Algorithm	CRT-18-04b-TRL4-TVALP-008.001	Characteristics taken from 10m anemometer wind measurements can be used for Bora wind classification algorithm.	Average result of 4.23/5 showed that validation participants agree that classification algorithm with data from 10m anemometer measurement recognizes Bora episodes.	OK
OBJ-18-04b-TRL4-TVALP-008	Bora Wind Classification Algorithm	CRT-18-04b-TRL4-TVALP-008.002	Characteristics taken from 10m anemometer wind measurements can be used to classify	Average results of 4.15/5 for standard Bora, 3.85/5 for deep Bora and 4.31/5 for gap flow show that validation participants agree	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
			different Bora types.	that classification algorithm with data from 10m anemometer measurements recognizes Bora types correctly.	
OBJ-18-04b-TRL4-TVALP-008	Bora Wind Classification Algorithm	CRT-18-04b-TRL4-TVALP-008.003	Bora classification algorithm correctly recognizes start and end of Bora episodes.	Average results of 3.92/5 for standard Bora and 3.77/5 for gap flow show that validations participants agree that Bora classification algorithm correctly recognizes start and end of Bora episodes. Average result of 3.15/5 for deep Bora was below pre-determined margin, but it was concluded that it is acceptable result from MET perspective because deep Bora is extremely complex wind flow and that even this first version of classification algorithm could be of great help for operational forecaster for	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
				improving situational awareness.	
OBJ-18-04b-TRL6-TVALP-009	Glideslope wind profile	CRT-18-04b-TRL6-TVALP-009.001	Cross- and headwind components derived from Weather Radar or Doppler Lidar show good correlation with alternative measurement available (e.g. AMDAR or 10 m winds at touchdown).	This is the case, but it has to be noted that the quality of the correlation is subject to the adequate siting of the Doppler Lidar or Radar instrument, since they only measure the radial component of the wind vector.	OK
OBJ-18-04b-TRL6-TVALP-009	Glideslope wind profile	CRT-18-04b-TRL6-TVALP-009.002	The glide slope wind profile can be obtained to cover the final approach area.	Realised in Exe for some runways (depends on actual siting).	OK
OBJ-18-04b-TRL6-TVALP-009	Glideslope wind profile	CRT-18-04b-TRL6-TVALP-009.003	The glide slope wind profile can be provided with an high update rate of 1 min.	This is not a feature of the glidepath wind product, but of the sensor infrastructure used. If the scanning speed of the devices is fast enough, an update rate of 1 minute can be achieved. In the	Partially OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
				campaign, only a lower update rate was feasible.	
OBJ-18-04b-TRL2-TVALP-010	Glideslope wind profile service	CRT-18-04b-TRL2-TVALP-010.001	Review of design of the glide slope wind profile service is done and shows that the service complies with the requirements.	“Service” is a capability, but its design fulfils the requirements.	OK
OBJ-18-04b-TRL6-TVALP-011	Switch of MET Product provider	CRT-18-04b-TRL6-TVALP-011.001	Connection to second provider is successfully established.	Connection to DLR via https established and files received.	OK
OBJ-18-04b-TRL6-TVALP-011	Switch of MET Product provider	CRT-18-04b-TRL6-TVALP-011.002	METForTAM service is correctly provided with GWMS proprietary convection algorithm.	METForTAM output generated with standard convection product of GWMS from LDO.	OK
OBJ-18-04b-TRL6-TVALP-011	Switch of MET Product provider	CRT-18-04b-TRL6-TVALP-011.003	METForTAM service is successfully swapped to new input using RadTRAM convection algorithm.	METForTAM output generated with convection product based on RadTRAM algorithm from DLR by simply swapping input sources.	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
OBJ-18-04b-TRL6-TVALP-011	Switch of MET Product provider	CRT-18-04b-TRL6-TVALP-011.004	Gaps in convection product data elements within METForTAM service are documented.	Only two parameters could not be filled, but DLR provides information for wider area.	OK
OBJ-18-04b-TRL4-TVALP-012	Runway Weather Monitoring and Forecast Service (input) -RWYWeather provision	CRT-18-04b-TRL4-TVALP-012.001	The service is providing all the data used for PJ.03b-06 validation.	Data sent using the Runway Weather Monitoring and Forecast Service (input) (RWYWeather service) and data received from the service are the same so the service does not deteriorate quality of data.	OK
OBJ-18-04b-TRL4-TVALP-012	Runway Weather Monitoring and Forecast Service (input)-RWYWeather provision	CRT-18-04b-TRL4-TVALP-012.002	Maximal delay resulting from service use is no greater than 3 min.		OK
OBJ-18-04b-TRL4-TVALP-012	Runway Weather Monitoring and Forecast Service (input)-RWYWeather provision	CRT-18-04b-TRL4-TVALP-012.003	The data can be disseminated in SWIM format.		OK
OBJ-18-04b-TRL4-TVALP-013	Runway Weather Monitoring and Forecast Service	CRT-18-04b-TRL4-TVALP-013.001	The service is handling dissemination of RCR according to	Data sent using the Runway Weather Monitoring and Forecast Service (output) and data	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
	(output) provision		new ICAO regulations [64][65][66]	received from the service are the same so the service does not deteriorate quality of data.	
OBJ-18-04b-TRL4-TVALP-013	Runway Weather Monitoring and Forecast Service (output) provision	CRT-18-04b-TRL4-TVALP-013.002	The service is handling dissemination of any additional relevant material (e.g. Predicted RCR as proposed by PJ.03b-06)	However, dissemination of full time series of Predicted RWYCC were not addressed.	Partially OK
OBJ-18-04b-TRL4-TVALP-014	Remote Tower MET Service provision	CRT-18-04b-TRL4-TVALP-014.001	The Remote Tower MET Service is correctly provided to airport stakeholders.	Data sent using the Remote Tower MET Service and data received from the service are the same so the service does not deteriorate quality of data.	OK
OBJ-18-04b-TRL4-TVALP-015	Airport MET Camera Imagery	CRT-18-04b-TRL4-TVALP-015.001	Camera provided series of stitched all sky imagery suitable for automatic recognition and remote observer observation of clouds.	The camera rotates and tilts in regular way and takes picture in all directions and elevations to cover half-sphere of sky above the camera. Stitching of pictures is applied in order to obtain one whole sky image projected to the plane.	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
OBJ-18-04b-TRL4-TVALP-015	Airport MET Camera Imagery	CRT-18-04b-TRL4-TVALP-015.002	Camera provided series of visibility landmarks imagery suitable for automatic recognition and remote observer observation of prevailing visibility.	The Camera takes picture of horizon in all cardinal and intercardinal directions with higher resolution to enable identify visibility landmarks by MET Observer or computer-based picture recognition algorithms.	OK
OBJ-18-04b-TRL4-TVALP-015	Airport MET Camera Imagery	CRT-18-04b-TRL4-TVALP-015.003	Camera provided video sequences of phenomena.	The camera records regularly in 10 minutes interval short (10 seconds) video of reference area to support recognition of some weather phenomena	OK
OBJ-18-04b-TRL6-TVALP-016	Cb-global contributes to flight safety	CRT-18-04b-TRL6 TVALP-016.001	At least one example where Cb-global information contributes to flight safety	For historical events it could be shown that Cb-global provides the situational awareness of the thunderstorm situation, and enables the pilot to optimize the measures to be taken (e.g. plan a safe route around the thunderstorms)	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
OBJ-18-04b-TRL6-TVALP-017	Cb-global contributes to fuel efficiency	CRT-18-04b-TRL6 TVALP-017.001	At least one example where Cb-global information contributes to fuel savings	A statistics has been established and real flown flight routes have been compared with flight routes optimized on the basis of Cb-global information. Both show considerable fuel savings if Cb-global is used for the flight planning	OK
OBJ-18-04b-TRL4-TVALP-018	Contrail formation	CRT-18-04b-TRL4 TVALP-018.001	To provide a set of specific real-world examples when contrail formed and where aircraft measurement were performed.	Contrail formation has been calculated and regions of persistant contrail formation have been identified, using observational and reanalysis data.	OK
OBJ-18-04b-TRL6-TVALP-019	Cb-global yellow profile service	CRT-18-04b-TRL6 TVALP-019.001	Cb-global information is transferred via a yellow profile service to a provider of up- and downlink services.	Cb-global has been operated in real time mode and transferred GML/XML files to an https interface where partners from PJ18-04c grabbed the data and used it as input for their validation EXE [50][51]	OK

Table 5: Summary of Technical Validation Exercises Results

4.2 Detailed analysis of SESAR Technological Solution Validation Results per Validation objective

Since the Validation objectives have been derived specifically for different Validation exercises, there is no consolidated view and analysis applicable per Validation objective. This is due to the nature of PJ.18-04b as technological and enabling solution where different partners developed different capabilities in dependency with different operational solutions. Below a short summary per objective is given and this relates to one exercise only.

4.2.1 OBJ-18-04b-TRL6-TVALP-001 Results

This objective belongs to Appendix E Technical Validation Exercise #05 (EXE-18-04b-TRL6-004_LDO “GWMS SWIM Enhancement”).This objective had the aim “to validate that the GWMS as local 4DWxCube fulfils general SWIM functionalities and settings required to provide and receive SWIM services”.

As a first success criterion, CRT-18-04b-TRL6-TVALP-001.001, it is listed that it is to be “possible to provide MET Information as SWIM services to stakeholders”. This has been shown by the fact that the METAR service has been provided on a request-reply and a publish-subscribe basis over a purple profile compliant SWIM node in EXE-17.01-TRL6-TVALP-EXE1.0001. Therefore, given the assumptions stated above, application of both profiles so far relevant for MET services, i.e. YP and PP, is feasible. The fact that in VAL EXE PJ.04.02-V2.04 in PJ04-02 there was no SWIM node over which the METForTAM service has been provided, but a broker simply following the AMQP 1.0 standard is deemed no issue, because subscription handling including authentication, encryption etc. has been shown in the EXE-17.01-TRL6-TVALP-EXE1.0001 for PP which is not a fundamentally different process than in YP.

The second success criterion, CRT-18-04b-TRL6-TVALP-001.002, demands that it be possible to accommodate new SWIM services without major redesign of the GWMS. This has been shown by the seamless integration of the METForTAM service in VAL EXE PJ.04.02-V2.04 in PJ04-02.

CRT-18-04b-TRL6-TVALP-001.003 asked that the GWMS be able to support 10000 subscriptions simultaneously. As this was not part of either exercise, this could not be tested. However, since the GWMS takes only the role of a service provider and the decoupling of provider and consumer is the job of the SWIM TI, it is proposed that this SC be not applicable.

CRT-18-04b-TRL6-TVALP-001.004 says that “the GWMS authentication by users is done between SWIM nodes”. This criterion is misleading since the authentication of a service provider and/or consumer is done between the client and the SWIM Node. This, however, has been demonstrated in EXE-17.01-TRL6-TVALP-EXE1.0001.

CRT-18-04b-TRL6-TVALP-001.005 requires the GWMS to allow the configuration of SSL-based transport protocol (AMQPS) for metadata and data transfer to maintain data security. Since AMQPS has been successfully used in VAL EXE PJ.04.02-V2.04 in PJ04-02, this one was successful.

CRT-18-04b-TRL6-TVALP-001.006, is not testable, but only to be validated by review of design: “The GWMS is designed according to Service-oriented architecture (SOA) principles.” However, since the SOA principle is at the core of the GWMS prototype, this one is fulfilled.

CRT-18-04b-TRL6-TVALP-001.007, "The GWMS allows issuing alerts to indicate that parts or all of the MET Information of a service is not available, out of date or cannot be generated." Could not be shown, because this is currently not foreseen in the design of any of the MET services. To some extent, this is implicitly provided by the METForTAM payload, because its design also shows empty tags for the products not provided. However, in case such alerting is explicitly required by a service, the design of the GWMS is fit for purpose. Internally it already uses such a scheme.

CRT-18-04b-TRL6-TVALP-008, "The GWMS delivers MET Services to local ATM consumers within a maximum delivery time depending on the MET product" contains a non-functional performance requirement which was not included and tested in any exercise.

CRT-18-04b-TRL6-TVALP-009,"The GWMS delivers MET Services to local ATM consumers using either SWIM Yellow or Purple Profile.", was implicit in both EXEs.

CRT-18-04b-TRL6-TVALP-010, "The GWMS provides services compliant with the latest releases of SESAR AIRM and ISRM except when duly justified." is a service requirement that is however fulfilled by METForTAM.

4.2.2 OBJ-18-04b-TRL6-TVALP-002 Results

This objective belongs to Appendix E Technical Validation Exercise #05 (EXE-18-04b-TRL6-004_LDO "GWMS SWIM Enhancement").

This is an essential objective for any publish/subscribe service. For the time being and the use of prototypes in validation exercises the objective was fulfilled by subscribing/unsubscribing actions to a service. A dedicated API of GWMS is not in line with the SOA principle as it is the Services Interfaces through which communication with consumers is facilitated. YP and PP services are fully supported and can be subscribed to or delivered to consumers. Change or deletion of the respective requirement is proposed.

4.2.3 OBJ-18-04b-TRL6-TVALP-003 Results

This objective belongs to Appendix E Technical Validation Exercise #05 (EXE-18-04b-TRL6-004_LDO "GWMS SWIM Enhancement").

This objective is fully covered by providing METAR as standard message but newly as PP service (so far only as YP service available). According to the assumptions, it is to be noted that the METForTAM service is a very complex service specifically developed for TAM concept.

4.2.4 OBJ-18-04b-TRL6-TVALP-004 Results

This objective belongs to **¡Error! No se encuentra el origen de la referencia.** Technical Validation Exercise #05 (EXE-18-04b-TRL6-004_LDO "GWMS SWIM Enhancement").

During EXE-17.01-TRL6-TVALP-EXE1.0001 using the technical infrastructure platform for PP, the provision of PP service by GWMS has been demonstrated using Request/Reply and Publish/Subscribe message exchange patterns.

4.2.5 OBJ-18-04b-TRL6-TVALP-005 Results

This objective belongs to Appendix E**¡Error! No se encuentra el origen de la referencia.** Technical Validation Exercise #05 (EXE-18-04b-TRL6-004_LDO "GWMS SWIM Enhancement").

In line with the objective OBJ-18-04b-TRL6-TVALP-004, GWMS demonstrated not only the provision of PP services but also the ability to subscribe, receive and unsubscribe to a PP service. The objective has been fully validated by receiving a PP service from an A/C.

4.2.6 OBJ-18-04b-TRL4-TVALP-006 Results

This objective belong to Appendix C Technical Validation Exercise #03 (EXE-18-04b-TRL4-001_CCL ''Bora wind detection'').

This objective had the aim ''to validate that dangerous runway crosswinds (Bora wind), and phenomena associated with Bora, in the vicinity of Dubrovnik airport, can be observed by Doppler Wind Lidar.''

Validation has been done to assess the three success criteria.

First was CRT-18-04b-TRL4-TVALP-006.001 ''Lidar data confirms north-east wind (runway crosswind) at lowest levels and approach area.'', about what validation participants expressed agreement with the result 4.88/5, after being shown relevant lidar scans during the workshop.

Second was CRT-18-04b-TRL4-TVALP-006.002 ''Height of Bora wind layer can be detected from lidar images.'', about what validation participants agreed with average result of 4.31/5, after being shown relevant lidar scans during the workshop.

Third was CRT-18-04b-TRL4-TVALP-006.003 ''Heterogeneous wind flows, which could represent turbulent areas, can be detected from lidar images.'', about what validation participants agreed with average result 4.31/5, after being shown prepared lidar scans during the workshop.

4.2.7 OBJ-18-04b-TRL4-TVALP-007 Results

This objective belong to Appendix C Technical Validation Exercise #03 (EXE-18-04b-TRL4-001_CCL ''Bora wind detection'').

This objective had the aim ''to validate that dangerous wind variations (wind shear) in Bora wind in the vicinity of Dubrovnik airport can be observed by Doppler Wind Lidar.''

Validation has been done to assess the two success criteria.

First success criteria was CRT-18-04b-TRL4-TVALP-007.001 ''Wind shear in approach to the Dubrovnik airport can be detected from lidar images.'', about what validation participants agreed with average result 4.63/5, after being shown prepared lidar scans during the workshop.

Second was CRT-18-04b-TRL4-TVALP-007.002 ''Wind rotors and wind shear in vicinity of Dubrovnik airport can be detected from lidar RHI (vertical) and PPI (horizontal) images.'', about what validation participants agreed with average result 4.25/5, after being shown prepared lidar scans during the workshop.

4.2.8 OBJ-18-04b-TRL4-TVALP-008 Results

This objective belong to Appendix D Technical Validation Exercise #04 (EXE-18-04b-TRL4-002_CCL ''Bora wind detection'').

This objective had the aim ''to validate that the Bora wind classification algorithm can be run on measurements derived from available MET infrastructure and provide correct classification results.''

Validation has been done to assess the three success criteria.

Success criterion CRT-18-04b-TRL4-TVALP-008.001 ''Characteristics taken from 10m anemometer wind measurements can be used for Bora wind classification algorithm.'' was achieved by validation participants expressing agreement that classification algorithm recognizes Bora episodes with average result 4.23/5.

Success criterion CRT-18-04b-TRL4-TVALP-008.002 ''Characteristics taken from 10m anemometer wind measurements can be used to classify different Bora types.'' was achieved by validation participants expressing agreement with the average result 4.15/5 for standard Bora, 3.85/5 for deep Bora and 4.31/5 for gap flow. Slightly lower result for deep Bora was somewhat expected because during deep Bora episodes, there are great variations in wind direction and speed on time scale of minutes and therefore having data every 30min is too coarse to capture deep Bora variations in such detail.

Success criterion CRT-18-04b-TRL4-TVALP-008.003 ''Bora classification algorithm correctly recognizes start and end of Bora episodes.'' was achieved by validation participants expressing agreement with the average result 3.92/5 for standard Bora and 3.77/5 for gap flow. Average result of 3.15/5 for deep Bora was below pre-determined margin 3.3/5, but it was concluded that it is acceptable result from MET perspective because deep Bora is extremely complex wind flow and that even this (first) version of classification algorithm could be of great help for operational forecaster for improving situational awareness.

4.2.9 OBJ-18-04b-TRL6-TVALP-009 Results

This objective belongs to Appendix A Technical Validation Exercise #01 (EXE-18-04b-TRL6-001_LDO "Glideslope wind profile").

A prototypical MET product inferring cross- and total wind representative of certain positions on the glidepath has been tested using Lidar data from a measurement campaign in Vienna Airport and respective Mode-S derived wind data. The main result of this exercise is that the quality of derived wind data can reach standard deviation on the order of 1.5 m/s against in situ measurements by aircraft, if the siting of the instrument is optimal with respect to the runway location and orientation. It could also be shown for a case of a gust front with sudden wind change that the spatially distributed information of the scanning devices can help mitigate such cases of large uncertainty by gaining a few minutes time for a pre-warning stakeholders depending on scan range and update rate.

The coverage depends strongly on the siting at the airport but in general can cover all runways and the 3NM extensions after threshold. The success criteria to provide wind information every minute was not met due to the executed scanning strategy.

4.2.10 OBJ-18-04b-TRL2-TVALP-010 Results

This objective belongs to Appendix B Technical Validation Exercise #02 (EXE-18-04b-TRL2-002_LDO "METForWTS").

The service has been designed according to received requirements and reviewed with respect to these in this exercise. The service payload is considered compliant. The results are satisfying and fulfil the requirements.

4.2.11 OBJ-18-04b-TRL6-TVALP-011 Results

This objective belongs to Appendix F **¡Error! No se encuentra el origen de la referencia.**.

The switch from one MET service provider to another one is fully feasible after pre-conditions have been considered. Pre-conditions are mapping of data elements and writing a converter to match data elements, which may have other names. All success criteria have been met for this objective which include the essential ones to establish connection to another provider and to finally distribute the MET product based on another data source.

4.2.12 OBJ-18-04b-TRL4-TVALP-012 Results

This objective belongs to Appendix H **¡Error! No se encuentra el origen de la referencia.**.

The following success criteria were considered:

- The service is providing all the data used for PJ.03b-06 validation
- Maximal delay resulting from service use is no greater than 3 min
- The data can be disseminated in SWIM format.

The results show that data sent using the Runway Weather Monitoring and Forecast Service (input) (RWYWeather service) and data received from the service are the same so the service does not deteriorate quality of data, therefore all three criteria were met.

4.2.13 OBJ-18-04b-TRL4-TVALP-013 Results

This objective belongs to Appendix H **¡Error! No se encuentra el origen de la referencia.**.

The following success criteria were considered:

- The service is handling dissemination of RCR according to new ICAO regulations.
- The service is handling dissemination of any additional relevant material (e.g. Predicted RCR as proposed by PJ.03b-06).

The results show that Data sent using the Runway Weather Monitoring and Forecast Service (output) and data received from the service are the same so the service does not deteriorate quality of data. However, dissemination of full time series of Predicted RWYCC were not addressed. The first criterion was met and the second was partially OK.

4.2.14 OBJ-18-04b-TRL4-TVALP-014 Results

This objective belongs to Appendix G Technical Validation Exercise EXE-18-04b-TRL4-001_LPS SR "Remote Tower MET Service" Report

The following success criterion was considered:

- The Remote Tower MET Service is correctly provided to airport stakeholders.

The results show that data sent using the Remote Tower MET Service and data received from the service are the same so the service does not deteriorate quality of data, therefore the criterion was met.

4.2.15 OBJ-18-04b-TRL4-TVALP-015 Results

This objective belongs Appendix I Technical validation exercise EXE-18-04b-TRL4-003_LPS SR "Airport MET Camera" Report.

The following success criteria were considered and with corresponding results:

- Camera provided series of stitched all sky imagery suitable for automatic recognition and remote observer observation of clouds

Result: the camera rotates and tilts in regular way and takes picture in all directions and elevations to cover half-sphere of sky above the camera. Stitching of pictures is applied in order to obtain one whole sky image projected to the plane.

- Camera provided series of visibility landmarks imagery suitable for automatic recognition and remote observer observation of prevailing visibility

Result: the camera takes picture of horizon in all cardinal and intercardinal directions with higher resolution to enable identify visibility landmarks by MET Observer or computer-based picture recognition algorithms.

- Camera provided video sequences of phenomena

Result: the camera records regularly in 10 minutes interval short (10 seconds) video of reference area to support recognition of some weather phenomena.

All results were OK and criteria met.

4.2.16 OBJ-18-04b-TRL6-TVALP-016 Results

This objective is related to Appendix J Technical Validation Exercise #10 Report (EXE-PJ18-04b-TRL6-001_DLR "Cb-global capabilities") which describes the details of the exercise and the objectives reached.

Objective OBJ-18-04b-TRL6-TVALP-016 was to show that Cb-global is abel to detect and nowcast Cb, CIT, and HAIC and that the use of Cb-global information contributes to flight safety.

For historical events it could be shown that Cb-global provides the situational awareness of the thunderstorm situation including also HAIC, and CIT, and enables the pilot to optimize the measures to be taken, e.g. plan a safe route around the thunderstorms.

The success criterion CRT-18-04b-TRL6 TVALP-016.001 (At least one example where Cb-global information contributes to flight safety) has been reached and TRL 6 readiness has been demonstrated.

4.2.17 OBJ-18-04b-TRL6-TVALP-017 Results

This objective is related to Appendix J Technical Validation Exercise #10 Report (EXE-PJ18-04b-TRL6-001_DLR "Cb-global capability") which describes the details of the exercise and the objectives reached.

Objective OBJ-18-04b-TRL6-TVALP-017 was to show that Cb-global is able to detect and nowcast Cb, CIT, and HAIC , and that the use of Cb-global information contributes to fuel savings.

A statistics has been established and real flown flight routes have been compared with flight routes optimized on the basis of Cb-global information. Both show considerable fuel savings if Cb-global is used for the flight planning:

- On average 0,548 tonnes of potential fuel savings per flight
- Some cases result in a fuel saving potential up to 3 tonnes per flight
- some avoidance manoeuvers were not necessary at all
- landings at alternates can be avoided

The success criterion CRT-18-04b-TRL6 TVALP-017.001 (At least one example where Cb-global information contributes to fuel savings) has been reached and TRL 6 readiness has been demonstrated.

4.2.18 OBJ-18-04b-TRL4-TVALP-018 Results

This objective belongs to Appendix L Technical Validation Exercise #12 (EXE-18-04b-TRL4-003_DLR "Contrail formation").

The service has been designed according to requirements, evaluated and reviewed with respect to these in this exercise. The results by usage of observational data and numerical weather forecast data are satisfying and fulfil the requirements.

4.2.19 OBJ-18-04b-TRL6-TVALP-019 Results

This objective is related to Appendix K Technical Validation Exercise #11 Report (EXE-PJ18-04b-TRL6-002_DLR "Cb-global yellow profile service") which describes the details of the exercise and the objectives reached.

Objective OBJ-18-04b-TRL6-TVALP-019 was to build a service that delivers Met hazard information via a yellow profile to an Aircraft and Flight Specific Met Integration System.

Cb-global has been operated in real time mode and transferred GML/XML files to an https interface where partners from PJ18-04c grabbed the data and used it as input for their validation EXE[50][51].

The success criterion CRT-18-04b-TRL6 TVALP-019.001 (Cb-global information is transferred via a yellow profile service to a provider of up- and downlink services) has been reached and TRL 6 has been demonstrated.

4.3 Confidence in the Validation Results

4.3.1 Limitations of Technical Validation Results

The individual validation exercises and their objectives within the MET Information Domain focus often on specific problems, e.g. glideslope wind for wake vortex separation, Bora wind, or information for remote tower locations, hazardous weather, and etc. Therefore, limitations are apparently the very specific purpose for which the MET product or service is developed. Nevertheless, MET information can be adjusted to the demand e.g. move from small to big airport application, by using different data input sources, enhanced infrastructure, etc. This depends on the requests from airport and ANSP to the MET Service Provider.

4.3.2 Quality of Technical Validation Exercises Results

All TRL6 exercises have been performed with highest diligence according to scientific standards and with modern technologies of the latest state-of-the-art. We are therefore confident that the results are robust and of excellent quality.

4.3.3 Significance of Technical Validation Exercises Results

The same applies here as above for limitations. MET products and services are developed for specific environments and purpose, but can be extended to be useful for other applications as well. This may require another input source, adjusting spatial and temporal coverage, or how the content of the payload message is presented. Nevertheless, each of the validation exercises has been conducted thoroughly and the results show that the MET information provides benefit to the operational customers.

Repetitions of exercise runs is in most cases not relevant because the focus is on which product is provided and how it is distributed to the customer. If simplifications have been applied, this can be found in the respective chapter of the validation exercises.

The DLR validation EXEs have demonstrated the capabilities and high significance of Cb-global. In particular, it could be shown that Cb-global

- increases situational awareness
- contributes to optimize (precautionary) measures during flight
- enables the planning of smart flight routes that avoid a waste of fuel
- contributes to reduce costs

With growing air traffic and increasing thunderstorm activity and intensity in a changing climate, the significance of the use of Cb-global information will even more increase.

5 Conclusions and recommendations

5.1 Conclusions

The technical validation report contains results of all validation exercises with different maturity levels. Regarding the two TRL6 solutions proposed by PJ.18-04b, the following conclusions can be drawn:

Solution 1: GWMS enhancement, Glide Wind Profile capability and METForTAM service:

- Glideslope wind profile demonstrated in comparison with MODE-S data very useful input for separation planning. It showed also the application limitations in terms of abnormal situations like the passage of a gust front. As for every remote sensing measurement usefulness of data depends on the siting and therefore coverage of airport and runways in dependence of the viewing angle. This MET product reached clearly TRL6.
- GWMS Enhancement – SWIM: as local 4DWxCube the GWMS prototype demonstrated SWIM capability and compliance by building a MET-GATE FB in the Aerodrome ATM MET CC for MET Services for Yellow and Purple Profile using respective infrastructure setup provided by PJ.17-01. Down- and uplink services were part of the tests and demonstrated the TRL6 readiness.
- As a local 4DWxCube the GWMS prototype offers MET services but the message payload may depend on different inputs or the input could be swapped due to unavailability of one MET provider. This swapping has been successfully demonstrated for the convection elements of the METForTAM service. This exercise reached TRL6.

Solution 2: Cb-global capability and Cb-global service:

- The validation results with Cb-global highlight what can be done with satellite data today regarding the situational awareness and the nowcasting of hazardous phenomena for aviation like thunderstorms, convectively induced turbulence, and icing conditions. The Cb-global information gives an overview of the hazard situation and its severity. However, it also extends the limited view of the on-board radar by providing a broader picture of the areas that are free of hazards. It happens that a situation identified as hazardous on-board is exposed as harmless by the view of the satellite, i.e. the precautionary measures the have to be taken in hazardous situations can be optimized by using the satellite view as an additional information. The use of Cb-global as an additional strategic planning tool thus results in an operational benefit. This benefit will even increase, if the Cb-global information is used both in the air and on the ground for a common information sharing (CIS) and common decision making (CDM).

The following conclusions can be drawn regarding the other validation exercises:

- Linked with GWMS, the corresponding service METForWTS (MET for Wake Turbulence Separation) was only designed with Enterprise Architect and modelled in MEGA. Review of design was done during the validation exercise. Therefore, the maturity level is TRL2. The service should be fully developed in Wave 2 and provided to the consumer solution in a validation exercise.
- Contrail formation service was evaluated using different source of MET data, observational on-board and numerical weather-forecast showing that contrail forming regions can be identified.

Deviations between usage of different temporal resolution of data was evaluated, demonstrating TRL4.
- All other TRL4 exercises have demonstrated that success criteria were met and therefore the validation objectives were achieved.

5.1.1 Conclusions on SESAR Technological Solution maturity

The two solutions, proposed for TRL6 maturity assessment have demonstrated high maturity to be further refined for implementation. In particular:

- LEONARDO Germany GmbH exercises: the exercises demonstrated TRL6 readiness for the MET product or service. One service (METForTAM) was included in the validation exercise of the operational project (PJ.04-02) and has TRL6 readiness as well.

- Also the DLR exercises (EXE-PJ18-04b-TRL6-001 and EXE-PJ18-04b-TRL6-002) have demonstrated TRL 6 readiness for the Cb-global capability and the Cb-global yellow profile service.

Due to the fact that PJ.18-04b addresses developments of different maturity levels, it is difficult to precisely determine the maturity of PJ.18-04b in its entirety. However, as the emphasis is on the TRL6 solutions, it can be concluded that validation results show that these developments have reached target maturity level of TRL6.

5.1.2 Conclusions on technical feasibility

The conducted validation exercises of PJ.18-04b used available state-of-the-art technology and algorithms, therefore they are fully technically feasible for near-term operational applications and installations. Only the provision and setup of respective SWIM MET Service is still an ongoing issue where major improvements can still be made.

5.1.3 Conclusions on performance assessments

As a technological solution developing system capabilities and information services, performance assessments should be conducted by ATM solutions using these prototypes to assess the benefit. PJ.18-04b focusses on the technical feasibilities of these developments, the use in an operational context is beyond the scope of this solution.

5.2 Recommendations

The following recommendations can be provided:

- Training for pilots: They have to learn how to combine the on-board information with the information provided by Cb-global and include this in their decision making process.

- Design means for pilots: New beneficial measures for flight planning have to be defined that account for the availability of real time hazard information. This could be a task for SESAR2020 Wave 2 (e.g. within PJ18W2 Sol .57).

- Cb-global hazard data have to be disseminated and made available to pilots and other aviation stakeholders in order to enable the common evaluation of hazard information from different tools.

- Provision of tools that represent and display the hazard information and graphically enable the combination of the hazard information coming from different sources (Cb-global vs. on-board radar).

- Contrail formation service providing two distinct criteria should be integrated in current MET environments in order to expand current systems towards sustainable operations by integrating an initial step toward eco-efficient operations.

5.2.1 Recommendations for next phase

- Enhancing all the provided MET capabilities into full functional SWIM services.
- A long-term validation exercise (VLD) for the testing of handling of several services, and directly supporting the operational projects would be necessary to demonstrate the full capabilities of a local 4DWxCube and not only single capabilities. It is in an adequate environment for the two TRL 6 solutions where all functional blocks of the local 4DWxCube will be deployed on site at several airports and tailored to their specific needs where they can provide their full value.
- This should be realised in shadow –mode trials (depending on available MET data) to demonstrate the clear benefit compared to currently available MET data and data provision
- This would also help to refine requirements for MET data (more clear description) and in return revise/adjust maybe the operational concept if it depends strongly on the available MET input.
- Concerning the Runway Weather Monitoring and Forecast services, it is likely that the services will be further worked out to reach TRL6, therefore coordination/dependencies between Sol25 and PJ18 is expected.

5.2.2 Recommendations for updating ATM Master Plan Level 2

All CRs related to newly created enablers are listed in Chapter 3.

5.2.3 Recommendations on regulation and standardisation initiatives

Newly developed MET product/capabilities should be checked if a SWIM service can be developed or the information can be applied to an already available SWIM service if not yet done. So far, still some proprietary data exchanges have been used for demonstrations. If the operational concepts clearly state the need for specific MET information, this should recommend the provision as a SWIM YP or PP service according to EUROCONTROL SWIM specifications.

6 References

6.1 Applicable Documents

Content Integration

[1] B.04.01 D138 EATMA Guidance Material

[2] EATMA Community pages

[3] SESAR ATM Lexicon

Content Development

[4] B4.2 D106 Transition Concept of Operations SESAR 2020

System and Service Development

[5] 08.01.01 D52: SWIM Foundation v2

[6] 08.01.01 D49: SWIM Compliance Criteria

[7] 08.01.03 D47: AIRM v4.1.0

[8] 08.03.10 D45: ISRM Foundation v00.08.00

[9] B.04.03 D102 SESAR Working Method on Services

[10]B.04.03 D128 ADD SESAR1

[11]B.04.05 Common Service Foundation Method

Performance Management

[12]B.04.01 D108 SESAR 2020 Transition Performance Framework

[13]B.04.01 D42 SESAR2020 Transition Validation

[14]B.05 D86 Guidance on KPIs and Data Collection support to SESAR 2020 transition.

[15]16.06.06-D68 Part 1 –SESAR Cost Benefit Analysis – Integrated Model

[16]16.06.06-D51-SESAR_1 Business Case Consolidated_Deliverable-00.01.00 and CBA

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[33]ICAO CAEP – "Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes" document, Doc 10031.

Security

[34]16.06.02 D103 SESAR Security Ref Material Level

[35]16.06.02 D137 Minimum Set of Security Controls (MSSCs).

[36]16.06.02 D131 Security Database Application (CTRL_S)

6.2 Reference Documents

[37]ED-78A GUIDELINES FOR APPROVAL OF THE PROVISION AND USE OF AIR TRAFFIC SERVICES SUPPORTED BY DATA COMMUNICATIONS.[3]

[38]Common assumptions for CBAs as maintained by Pj19 (provisionally the ones included in the 16.06.06- D68_Part 1, New CBA Model and Methods 2015, Edition 00.01.01 can be used)

[39]D4.2.210 PJ.18-04b TRL6 Technical Specifications (TS/IRS)

[40]D4.2.140 - 18-04b-TRL6 – TVALP Version V2.1 from 13 June 2019

[41]PJ.02-01, Increased runway and airport throughput, SPR-INTEROP/OSED for V3, edition 00.00.10, January 2019

[42]SESAR Solution PJ.03b-06 - V2 SPR-INTEROP/OSED - Part I, Ed. 00.02.00, April 2019

[43]SESAR Solution PJ.03b-06 TS-IRS for V2 (Interim), Ed. 00.01.01, March 2018

[44]SESAR Solution PJ.05-05 TVALP for TRL4

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Appendix A Technical Validation Exercise #01 Report (EXE-18-04b-TRL6-001_LDO "Glideslope wind profile")

A.1 Summary of the Technical Validation Exercise #01 Plan

This exercise followed the description as in the TVALP of project 18-04b despite the fact that only lidar data have been used. These have been collected during the measurement campaign conducted during validation EXE LT10 of PJ02-01 at Vienna airport, supporting the analysis of the benefit gained from wake decay enhancing devices by monitoring the relevant atmospheric parameter influencing wake decay and transport. The reason why only lidar data have been used for the present analysis of the glidepath wind is simply the fact that very little precipitation occurred during the campaign and Radar data are mostly empty.

The lidar data have been compared to MODE-S data kindly provided by Austrocontrol. The glide and departure path wind profiles have been calculated for 3 and 6 degree, respectively.

A.2 Technical Validation Exercise #01 description and scope

This is an internal technical validation supporting PJ.02-01 where needs for detailed wind information in the approach and departure paths have been identified. Wind information required comprises head- and crosswind components along the glideslopes and departure paths. These are needed for situational awareness in optimising the runway and airport throughput by addressing new arrival and departure concepts [41]. So far, this new product has not yet been used in any operational exercise.

Operational actors would include people in the Departure Separation Management FB and in the Operational Supervision Aerodrome ATC FB who need to receive, assess and display wind information. The dedicated service METForWTS (see Appendix B) shall be the carrier of this novel information.

This technical validation aims to compare the wind profiles extracted from Doppler Lidar radial velocity with aircraft derived wind data to demonstrate the reliability and assess the limitations of said profiles. To this end, the already available GWMS product ROSHEAR (LEONARDO Germany GmbH product for runway oriented wind shear) has been extended to provide also total and cross wind components for the three nautical miles forward segments on the 3° and 6° slant plane beyond runway thresholds. The algorithm has been run on Lidar data from 3° and 6° elevation scans. Lidar data have been obtained during the measurement campaign supporting PJ02-01 LT10 at Vienna airport during a period of 2.5 months from mid-June through end of August. The 3 degree elevation scan was available every 2-3 minutes, the 6 degree scans every 10-15 minutes.

Crosswind calculations pre-require determining the horizontal wind, if the radial wind is not measured exactly perpendicular to the runway centerline. Horizontal wind has been derived using with two different methods. The results of both methods have been compared with crosswind from the aircraft derived data.

The method of comparison can be described as follows:

1. A particular segment of the profile under scrutiny is chosen (1 nm x 1 nm)
2. For all derived profiles: Mode-S wind data are collected and assigned to a profile if

a. their times falls into the interval t ± 2 minutes, with t being the timestamp of the profile t_0 plus a forecast offset Δt (0≤Δt ≤10 min)

b. the A/C has a position that is in the box given by the respective segment and has altitude falling into the interval between the height of the middle of this segment and the next, the first one being the exception having a lower boundary of the runway (i.e. 0 m AGL).

3. All differences for the path segment are used to compute the standard deviation for the whole set and for the set of values for which the profile value lies below a threshold that is operationally used to switch operations (10 knots for total wind, 6 knots for crosswind)

A.3 Summary of Exercise #01 Technical Validation Objectives and success criteria

The validation objectives state that either Radar or Lidar data can be used. The validation has been executed with Lidar data only because availability of Radar data was limited due to mostly dry weather situations. Thus, the provided results and conclusions are only applicable to Lidar data, although the principle of data usage is the same. Differing apparatus functions and intrinsic errors as well as features characteristic for the respective measurement process such as the problem of fill-factors due to inhomogeneous precipitation fields diminish the direct transferability of the results obtained with lidar onto the same procedure using radar data. In order to obtain the exact numbers for radar, the analysis must be repeated with Radar data. Using both Radar and Lidar with a data fusion operation, all-weather availability of the wind profile product can be achieved (a standard procedure for runway oriented shear).

Identifier	Success Criterion
CRT-18-04b-TRL6-TVALP-009.001	Cross- and headwind components derived from Weather Radar or Doppler Lidar show good correlation with alternative measurement available (e.g. AMDAR or 10 m winds at touchdown).
CRT-18-04b-TRL6-TVALP-009.002	The glide slope wind profile can be obtained to cover the final approach area.
CRT-18-04b-TRL6-TVALP-009.003	The glide slope wind profile can be provided with an high update rate of 1 min.

The first and second success criteria are fulfilled. Details about correlation can be found in section A.7. The approach area can be covered but depends of course on the siting possibilities. So not all approach and departure areas can be fully covered. The third criterion is normally a standard when providing information about runway oriented shear, but in this measurement campaign, data were not available every minute.

The respective requirements associated with this exercise can be found in the TS of PJ18-04b [39] in sections 4.2.2 (Information and Alerting) and 4.2.3 (Measurements):

- REQ-18-04b-TS-CC31.0020: Glidepath Wind Profile
- REQ-18-04b-TS-CC31.0030: Glidepath Wind Profile Forecast
- REQ-18-04b-TS-CC42.0030: Very short term forecast wind field near the airport
- REQ-18-04b-TS-CC42.0040: Glidepath real time wind monitoring

A.4 Summary of Technical Validation Exercise #01 Validation scenarios

Reference scenario includes provision of wind information obtained only from wind sensors located at runway thresholds. Therefore, any information obtained along glide/climb paths are an advantage. High update rate (normally every minute) and spatial resolution of 1 NM are appropriate.

A.5 Summary Technical Validation Exercise #01 Assumptions

N/A

A.6 Deviation from the planned activities

Input data were obtained from the measurement campaign conducted in the scope LT10 of PJ02-01 in Vienna. Due to the weather situation Radar data was in most cases empty but Lidar delivered sufficient data. So only Lidar data was analysed covering 2.5 months from mid-June until end of August with some gaps in between.

Three and six degree elevation scans up to 3 NM beyond runway thresholds have been analysed for the runways at Vienna airport. Due to the siting of the Lidar sensor following areas could not be covered with sufficient data (for explanation of the naming convention of path segments see below and **¡Error! No se encuentra el origen de la referencia.**):

- Runway 11: 3MF, 2MF, partly 1MF
- Runway 16: 3MF, 2MF, partly 1MF
- Runway 34: 3MF, partly 2MF

The Scanning strategy had been selected to provide as high an update rate as possible for wind information. However, 3° scans have only been available every 2-3 minutes, and 6° scans every 10-15 minutes. Therefore, we miss the success criteria to provide information every minute. This is, however, not a principle limitation, but can be amended by using a different instrumentation (other and/or more devices), siting and scan strategy. It has to be understood that this was not possible in a temporary campaign.

Another limitation arising from the siting is due to the geometry of the Lidar line of sight and the runways in terms of crosswind determination. Since Doppler measurements deliver only the radial component of the wind, the visibility of crosswind is zero in the line of sight. Therefore, the ideal setup would be where the line of sight is perpendicular to the runway directions. A possible amendment would be also the usage of Dual-Doppler techniques employing two sensors at some distance apart. This limitation can be clearly seen when comparing the crosswind error distribution on Runway 16 1MF and Runway 29 2MF. See Figure 3 for the statistics. Note, however, that the quality of the total wind for runway 29 is still quite good.

For comparison MODE-S data have been used which is the better solution in terms of spatiotemporal coverage than AMDAR or data from 10 m wind at thresholds.

A.7 Technical Validation Exercise #01 Validation Results

A.7.1 Summary of Technical Validation Exercise #01 Results

Technical Validation Exercise #01 Validation Objective ID	Technical Validation Exercise #01 Validation Objective Title	Technical Validation Exercise #01 Success Criterion ID	Technical Validation Exercise #01 Success Criterion	Technical Validation Exercise #01 Results	Technical Validation Exercise #01 Validation Objective Status
OBJ-18-04b-TRL6-TVALP-009	Glideslope wind profile	CRT-18-04b-TRL6-TVALP-009.001	Cross- and headwind components derived from Weather Radar or Doppler Lidar show good correlation with alternative measurement available (e.g. AMDAR or 10 m winds at touchdown).	Cross- and headwind components show good correlation, if the angle of observation is near optimal. Total wind is less sensitive to the geometry of observation.	OK
OBJ-18-04b-TRL6-TVALP-009	Glideslope wind profile	CRT-18-04b-TRL6-TVALP-009.002	The glide slope wind profile can be obtained to cover the final approach area.	Approach and departure area can be monitored depending on siting and data availability.	OK

OBJ-18-04b-TRL6-TVALP-009	Glideslope wind profile	CRT-18-04b-TRL6-TVALP-009.003	The glide slope wind profile can be provided with a high update rate of 1 min.	Normally product can be obtained with high update rate of 1 min. But this was not realised for the measurement campaign.	Partially OK

Table 6: Technical Validation Results Exercise #01

Results on technical feasibility

The new information about total wind and crosswind for the three miles forward sections of the approach and departure paths derived from already existing product ROSHEAR shows good correlation with MODE-S data. General constraints are the coverage of glide/climb paths due to siting and the temporal resolution because of the chosen scheduler.

Results per KPA

N/A. For addressing KPAs please refer to [41].

A.7.2 Analysis of Exercise #01 Results per Technical Validation objective

OBJ-18-04b-TRL6-TVALP-009 Results

CRT-18-04b-TRL6-TVALP-009.001: Cross- and headwind components derived from Weather Radar or Doppler Lidar show good correlation with alternative measurement available (e.g. AMDAR or 10 m winds at touchdown)

As can be seen in Figure 2 and, the correlation of the Mode-S derived wind data and the lidar derived wind data (total wind and cross wind) on runway 16, two miles forward (2MF) is with $R^2 = 0.9$ quite good. The bias is considerably low for crosswind, while it is of discernible value for total wind. However, as will become apparent when the full data set is analysed that this depends strongly on the location considered, especially for cross wind. It should be noted that this is a fact that can be mitigated by different siting of the instrument and the use of more than one instrument. The latter also would open up the possibility to use a dual-Doppler strategy in order to derive horizontal wind.

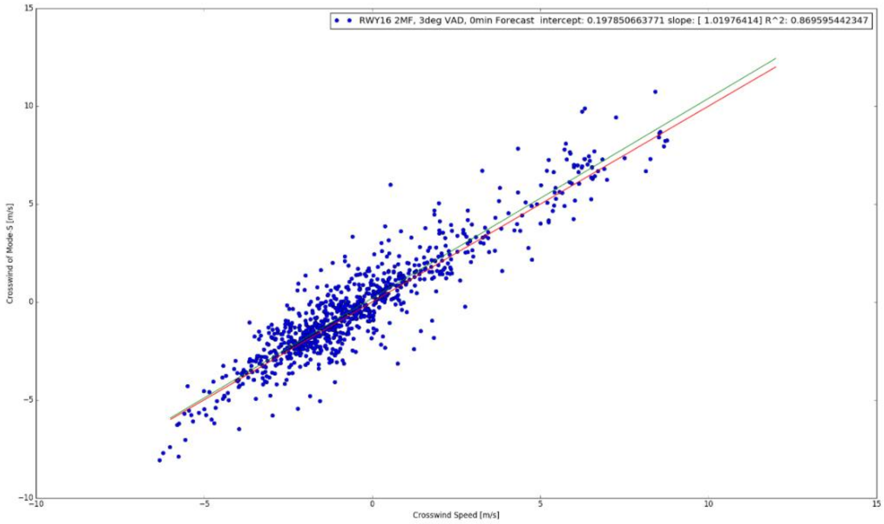


Figure 1: Plot of Mode-S crosswind vs crosswind derived from lidar data on the 3° path

Using VAD on runway 16 in the two mile foreward (2MF) segment (blue dots). The green line shows the linear regression line, while the red line indicates the line cross wind Mode-S = cross wind lidar

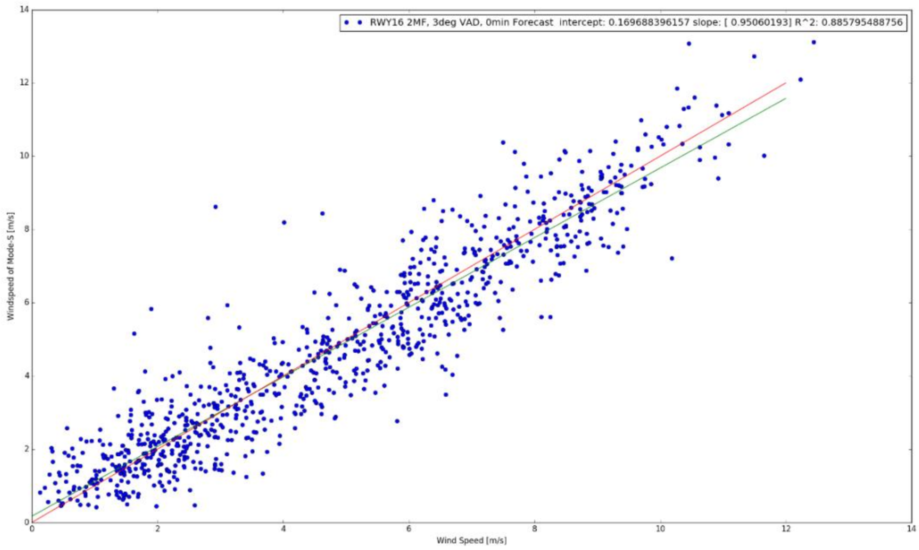


Figure 2: Plot of Mode-S wind speed vs wind speed derived from lidar data on the 3° path

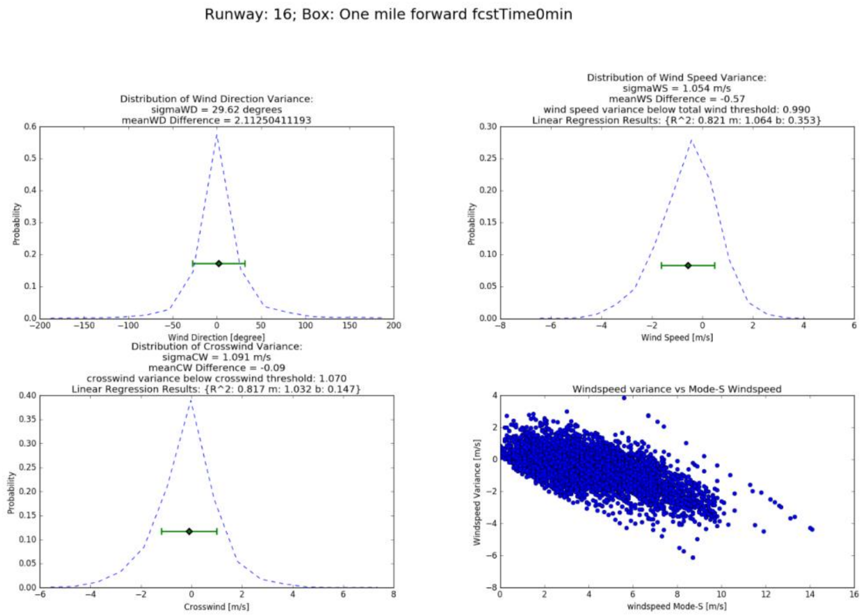
Using VAD on runway 16 in the two mile foreward (2MF) segment (blue dots). The green line shows the linear regression line, while the red line indicates the line wind speed Mode-S = wind speed lidar

Below, the detailed analysis of the glide path wind profiles derived using the VAD and the HWIND algorithms for 3° and 6° will be described.

Analysis for glide path wind derived using the VAD algorithm:

As can be seen in Figure 3 and 4, the standard deviation for total wind (sigma) on RWY 16, 1 MF, is about what can be expected for the combined measurement errors of the in-situ and the lidar measurement, given variations of wind inside the measured volume. On Runway 29, it is almost doubled which can be attributed to the fact that it is farther away from the lidar and that the cone surface of the 3° PPI-Scan coincides less with the 3° glide path on RWY 29 than it does with that on RWY 16. As to the 6° paths, one can observe that biases are lower than for 3°, while errors are slightly larger.

Correlation coefficients (R^2) from the linear regression with Mode-S data range from 0.9 on RWY 16, 2 MF and 3MF, for total wind and crosswind to 0.3 on RWY 29 1 MF, also for total wind and crosswind. It can be seen, as expected, that the crosswind component derived from the single lidar data is the better, the closer to perpendicular its line of sight is to the runway.



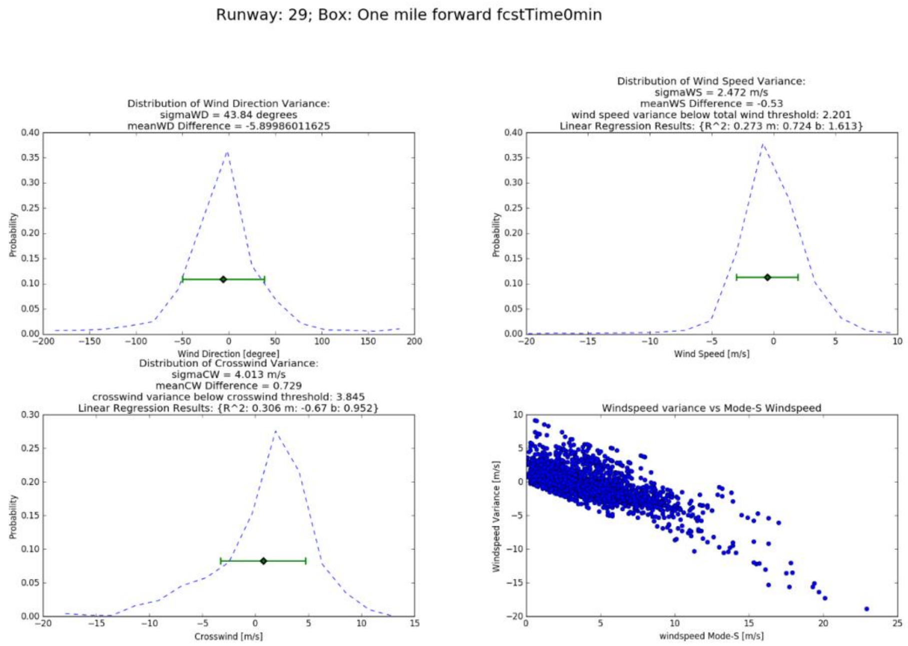
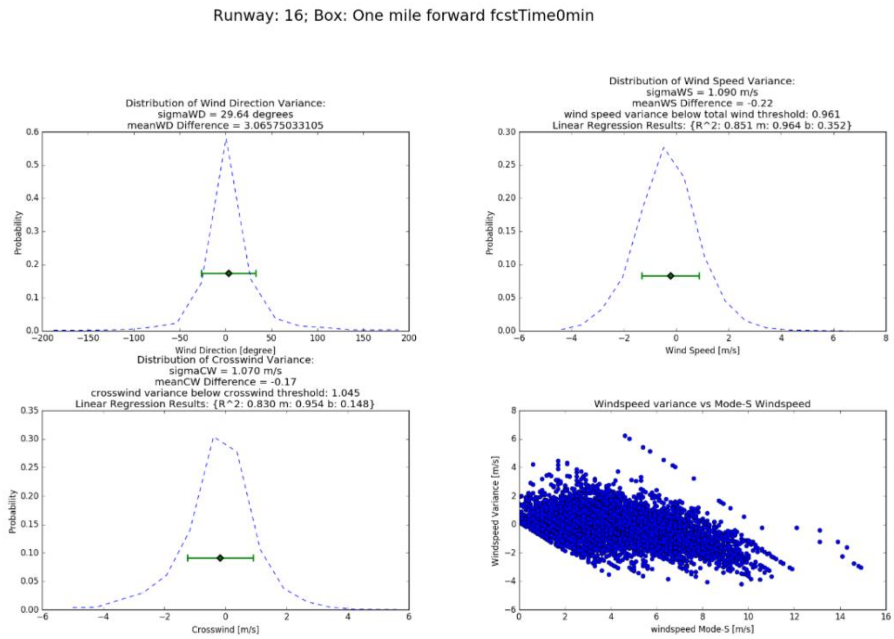


Figure 3: Statistics for glidepath profile 3°

Using VAD method for total wind, crosswind and wind direction for runway 16 1MF and runway 29 1MF at 0 minutes forecast: The large difference between the crosswind errors is because the geometry for 16 1MF is nearly ideal for the determination of cross wind, while for 29 it is almost worst case. This limitation holds not for total wind.



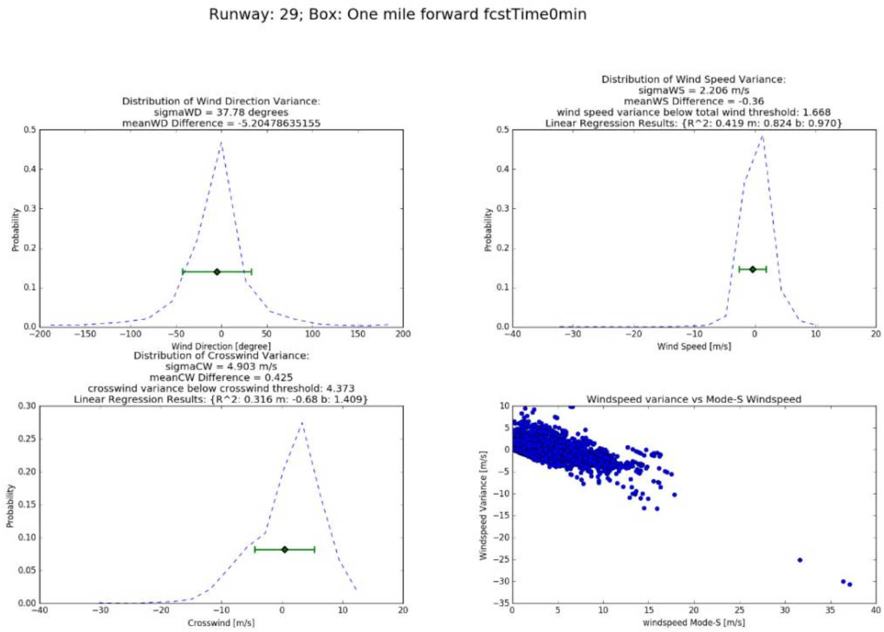


Figure 4: Statistics for glidepath profile 6°

Using VAD method for total wind, crosswind and wind direction for runway 16 1MF and runway 29 1MF at 0 minutes forecast: Compared to 3° it can be noted that correlation coefficients are larger and biases are lower. Since the latter is the general trend for the higher segments for 3°, it is likely that the bias is an effect that appears close to the ground where the wind profile changes strongest with height.

The negative bias for the difference profile total wind – total wind Mode-S in the lower left panel of Figure 3, that is, the underestimation of total wind compared to one measured by Mode-S varies from rather large and reproducible to small and fitful. For RWY 16 it is strongest for the 1MF segment and becomes much smaller for 2 and 3 MF.

Figure 5 and Figure 6 below show the standard deviations for all runways and all path segments, 3° and 6°, using the VAD algorithm (note that for VAD all three segments can be provided for all runways, whereas for HWIND, for some segments no values could be derived).

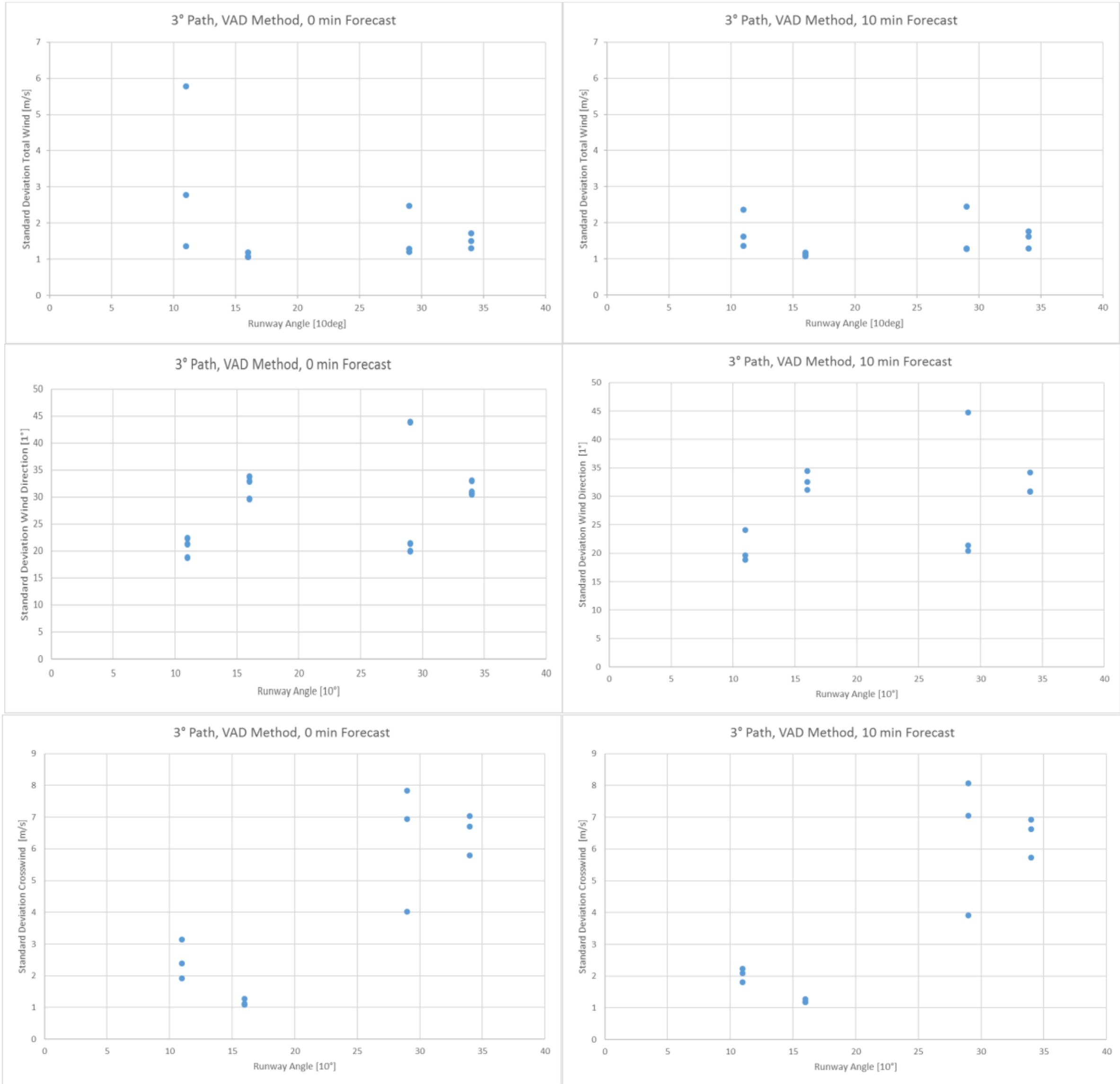


Figure 5: Comparison of standard deviations for different runways, current and forecast, for 3° glide path using VAD.

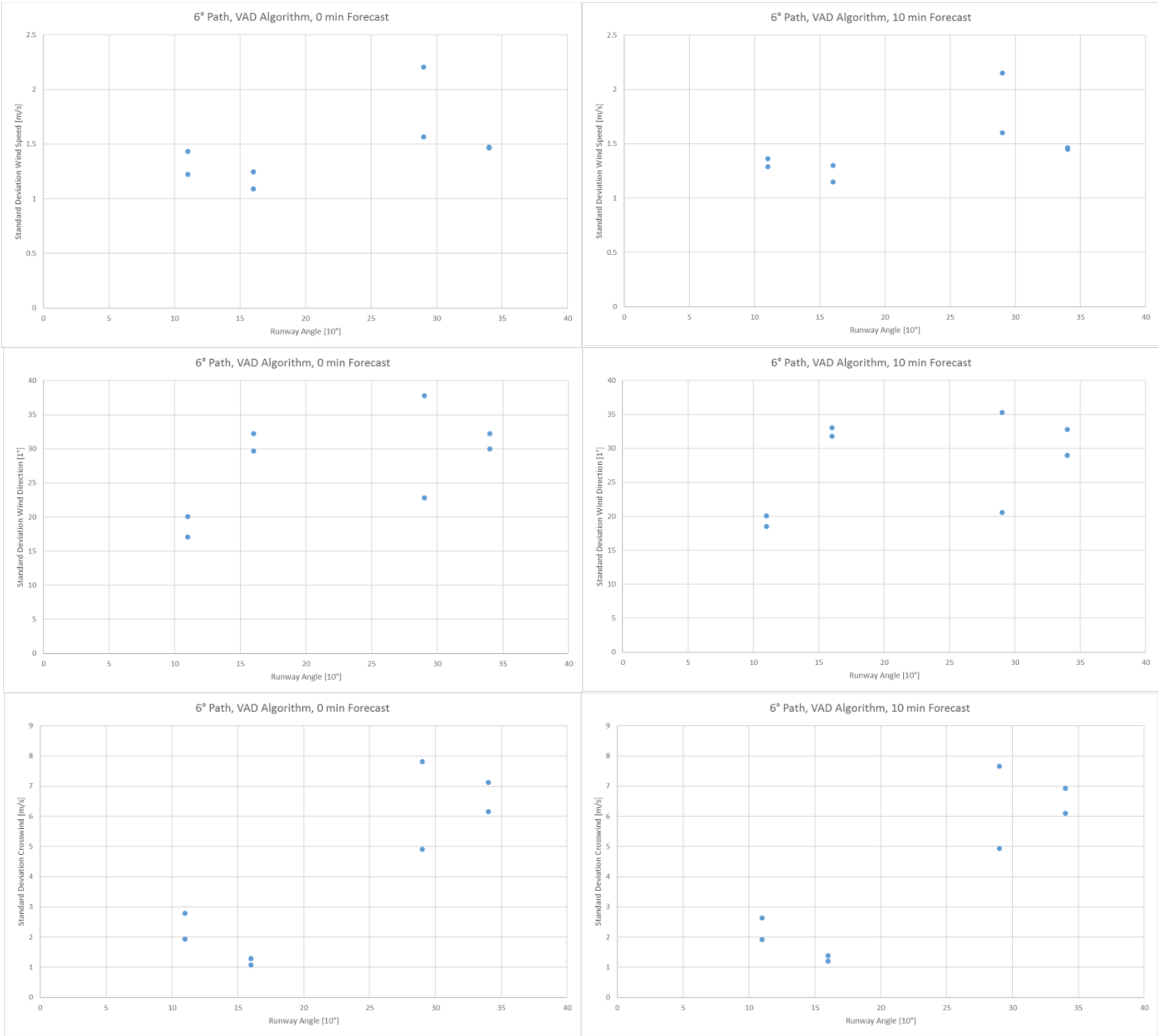


Figure 6: Comparison of standard deviations for different runways, current and forecast, for 6° path using VAD.

Note that for 3MF no Mode-S data for comparison have been found

<u>Analysis for glide path wind derived using the HWIND algorithm:</u>

Of the two algorithms VAD and HWIND, the latter is the one that uses the local radial wind field at the position where horizontal wind is to be evaluated, but is less robust than the VAD method which derives a global windprofile from one PPI scan, that is, the 3° or 6° PPI scan, respectively. Additionally, HWIND works not only on the PPI at the elevation angle in question, but uses the whole volume scanned and derives constant altitude PPIs (CAPPIs) from it. In the case of the Vienna campaign, 1.5°, 3° and 6° had been scanned. This means that it tries to find the wind information at the point in question, but it also means that it is more vulnerable to missing data and more prone to errors due to the fact that the perpendicular wind component is derived from the angular variation of the radial wind. This latter point further ensues a trade-off situation between spatial resolution and accuracy.

The smaller the volume considered, the smaller the difference in azimuth angle which in the limit of 0° has zero sensitivity for the perpendicular wind component (the derivative of the sine function is 0 at this point).

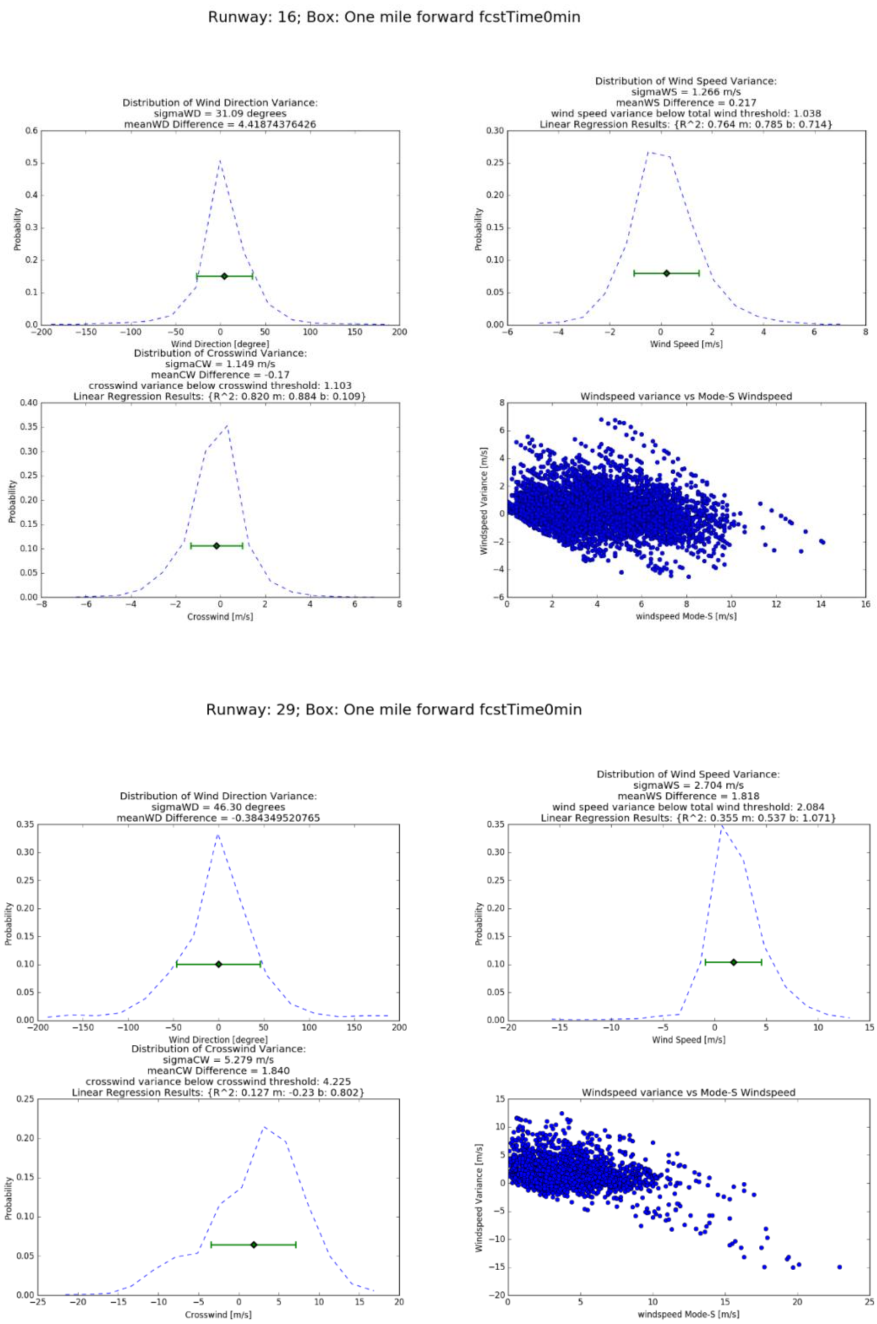
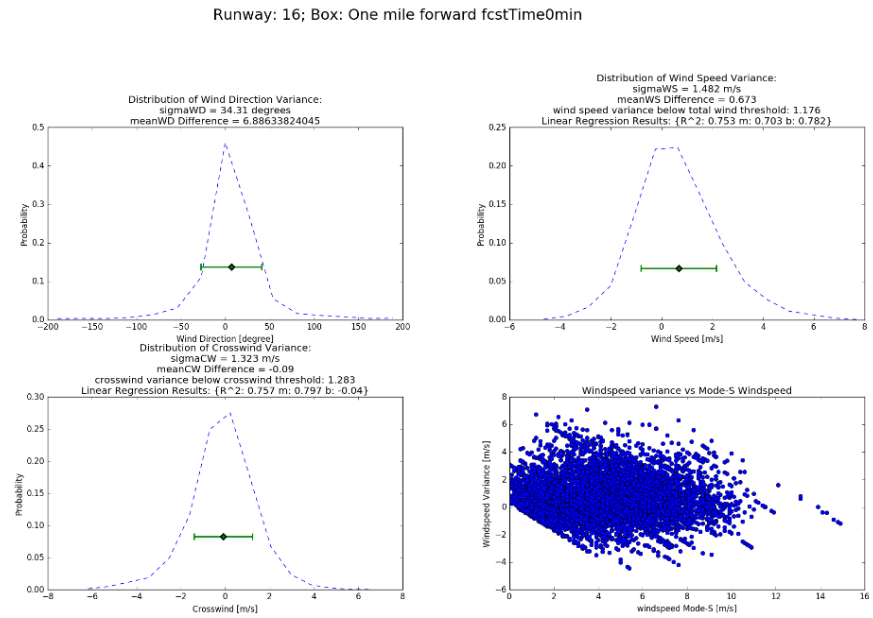


Figure 7: Statistics for glidepath 3° profile

Using HWIND method for total wind, crosswind and wind direction for runway 16 1MF and runway 29 1MF at 0 minutes forecast: The large difference between total wind and crosswind errors in the two locations is due to the geometry. For 16 1MF, it is nearly ideal for the determination of cross wind, while for 29 it is almost worst case. This limitation holds not for total wind.



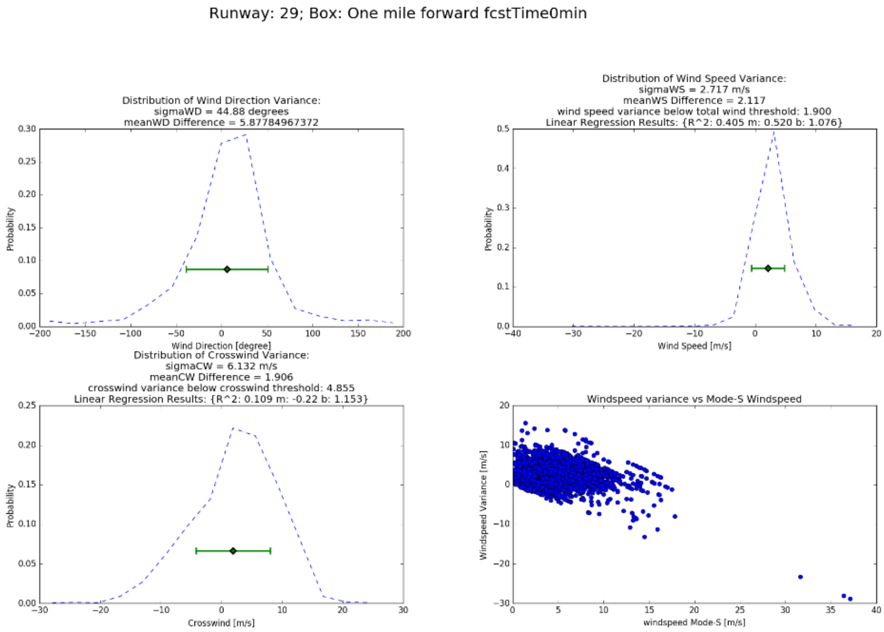


Figure 8: Statistics for glidepath 6° profile

Using HWIND method for total wind, crosswind and wind direction for runway 16 1MF and runway 29 1MF at 0 minutes forecast: The large difference between total wind and crosswind errors in the two locations is due to the geometry. For 16 1MF, it is nearly ideal for the determination of cross wind, while for 29 it is almost worst case. This limitation holds not for total wind.

From Figure 7 one learns that the general trend for HWIND is that the error is slightly larger than for VAD and that the negative bias of the difference wind speed profile minus Mode-S wind speed is much less pronounced (note that for RWY 16 1MF it is absent almost altogether).

Figure 9 and Figure 10 below show the standard deviations for all runways and all path segments, 3° and 6°, using the HWIND algorithm. For some segments no values could be derived. The reason for this lies in the fact that HWIND uses the local radial velocity information which for some segments is insufficient due to siting issues (sector blanking due to buildings).

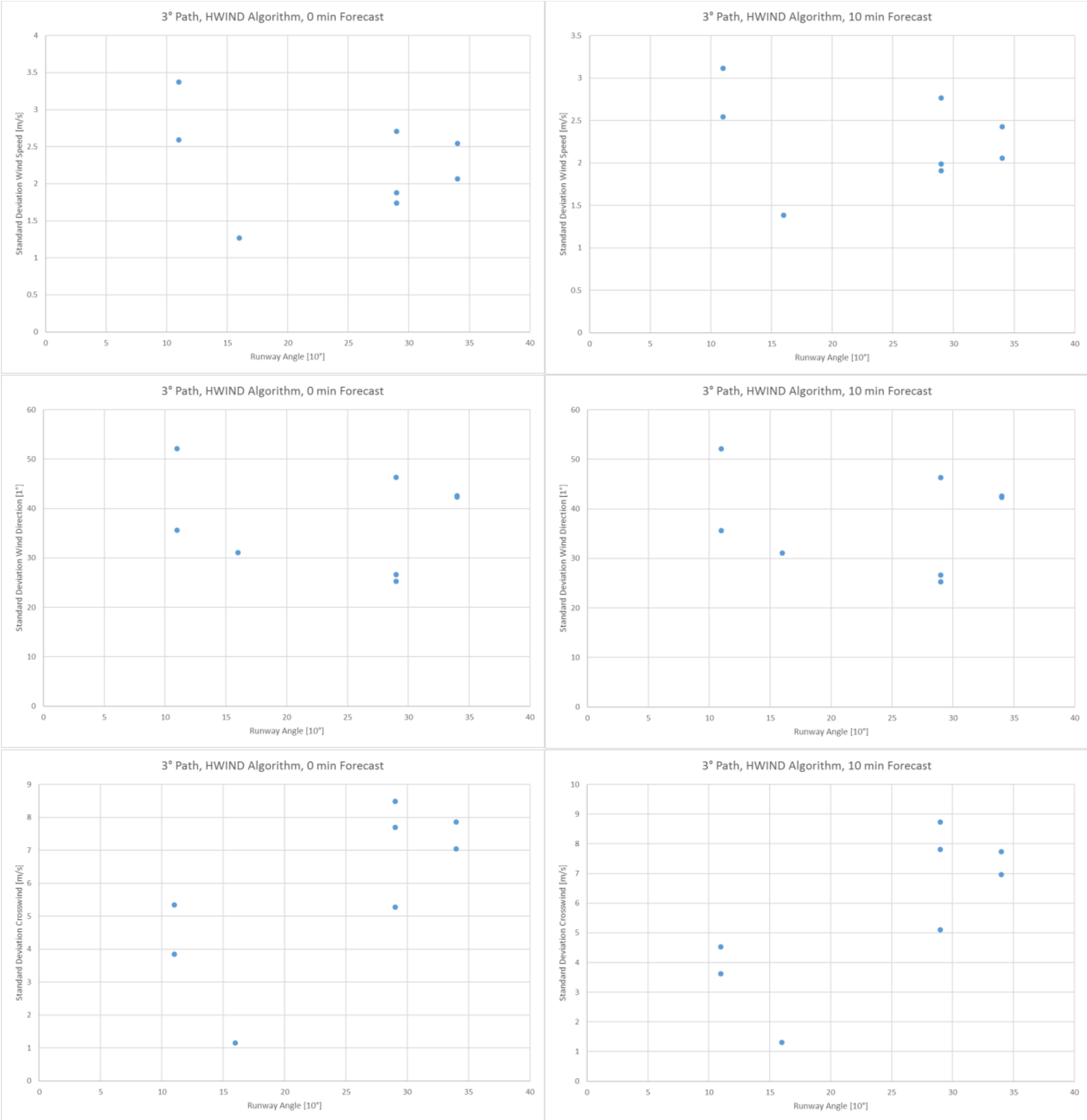


Figure 9: Comparison of standard deviations for different runways, current and forecast, for 3° glide path using HWIND

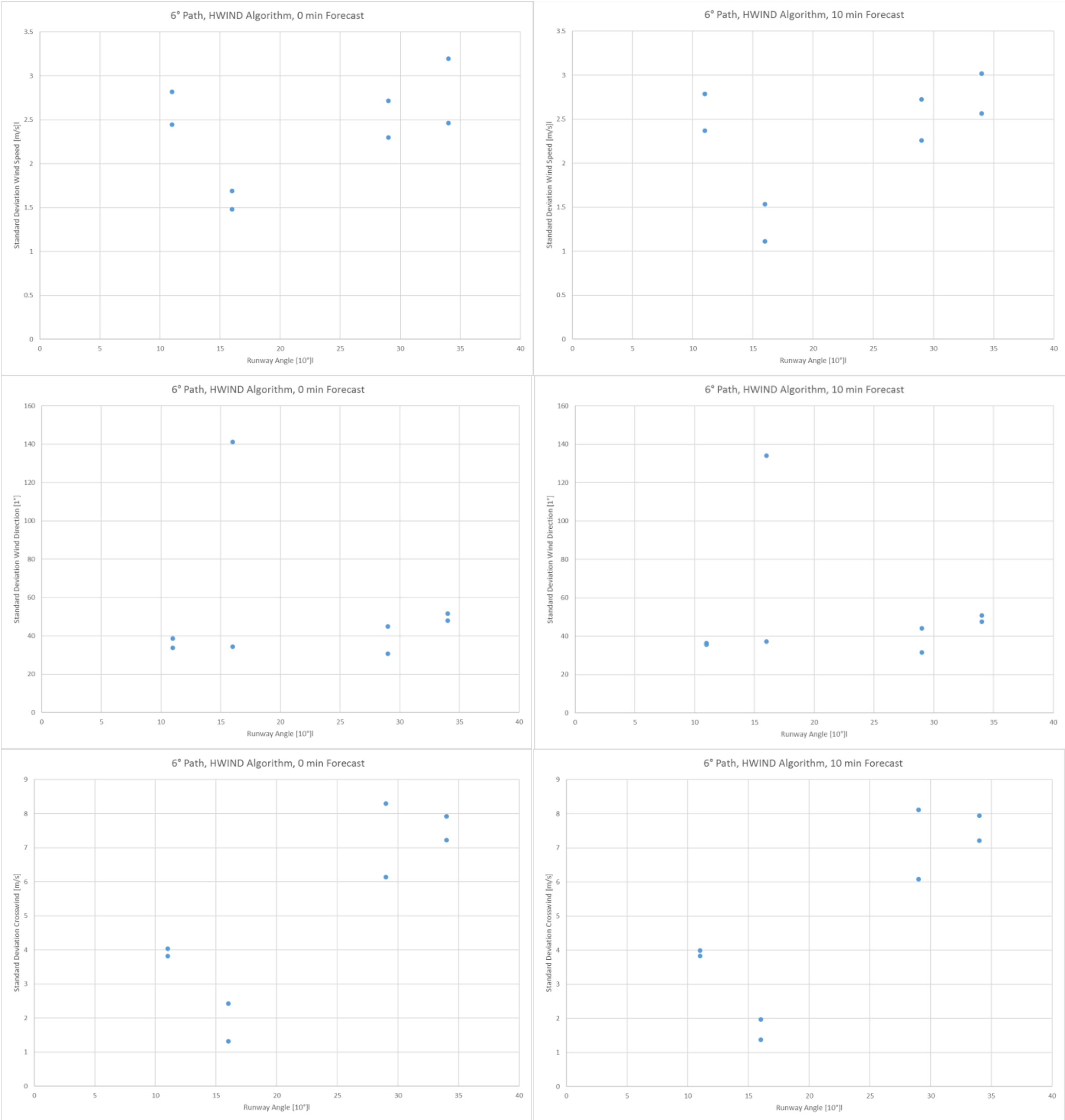


Figure 10: Comparison of standard deviations for different runways, current and forecast, for 6° glide path using HWIND

For completeness, Table 7 lists all statistical parameters derived for all segments of all runways.

Table 7: Statistics for all runways

Statistics_allRwys.xlsx

General features and mitigations:

One very prominent feature is that the quality of the correlation between Mode-S data and lidar derived path profiles does not degrade considerably for persistent forecasts of 1 to 10 minutes. However, a particular point that needs to be addressed is presented by the cases in which the variations are large compared to the mean values. For a possible deployment, such cases need to be studied in detail in order to derive methods to warn stakeholders about wind measurements no longer being reliable and safety margins used to account for the uncertainty are no longer valid.

It may be assumed that, beside the inherent quality of data, e.g. during fog conditions when both lidar and precipitation radar have no data, sudden changes in the wind field present the main scenarios in which this is the case. Considering the situation of stable wind conditions, it is not surprising that on average the quality of the correlation does not degrade much with forecast time as is seen in the data. The task is therefore to spot situations early on in which wind conditions become unstable. One such case has been analysed for this report. For a deployment, such analysis would need to be done for all such cases when deviations are larger than one or two sigma for a much more representative time interval (at least 1 year).

On July 1st 2019, a gust front moved across the Vienna airfield as can be seen in Figure 11 and Figure 12.

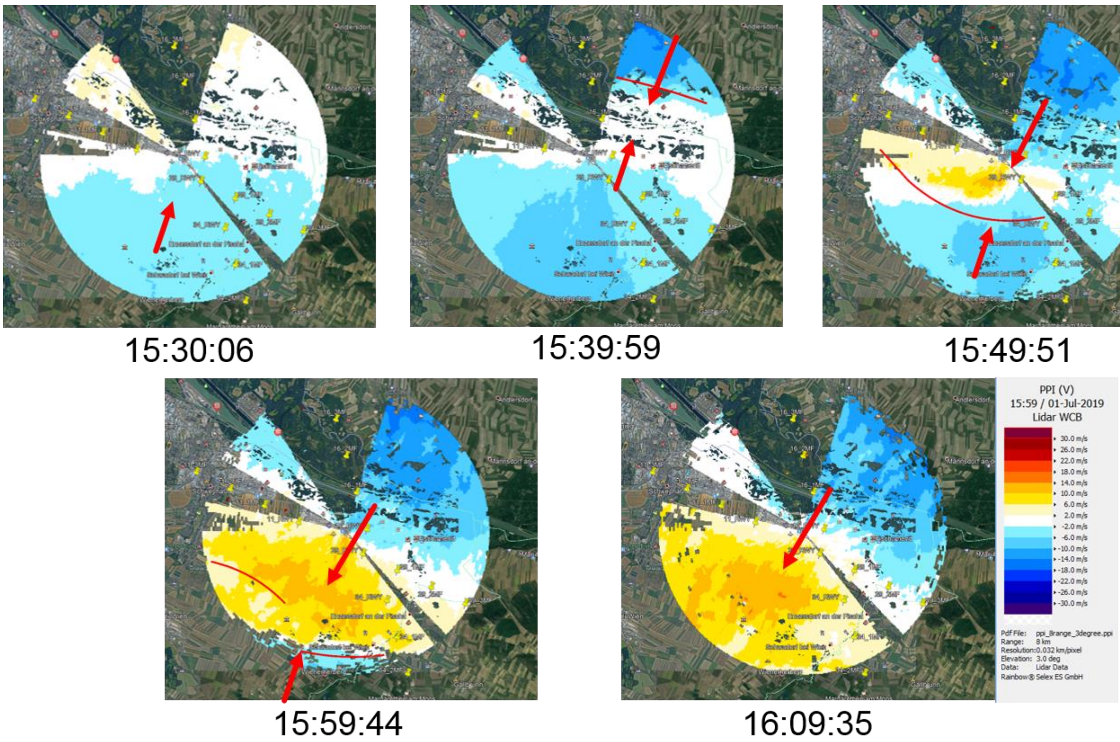


Figure 11: Gust Front (red line) moving across the airfield of Vienna airport on July 1st 2019.

Markers show middle points of glide path segments for all runways, radial velocity derived from lidar scan is shown in false colors conforming to the legend in the lowest right panel. Red arrows show approximate main flow.

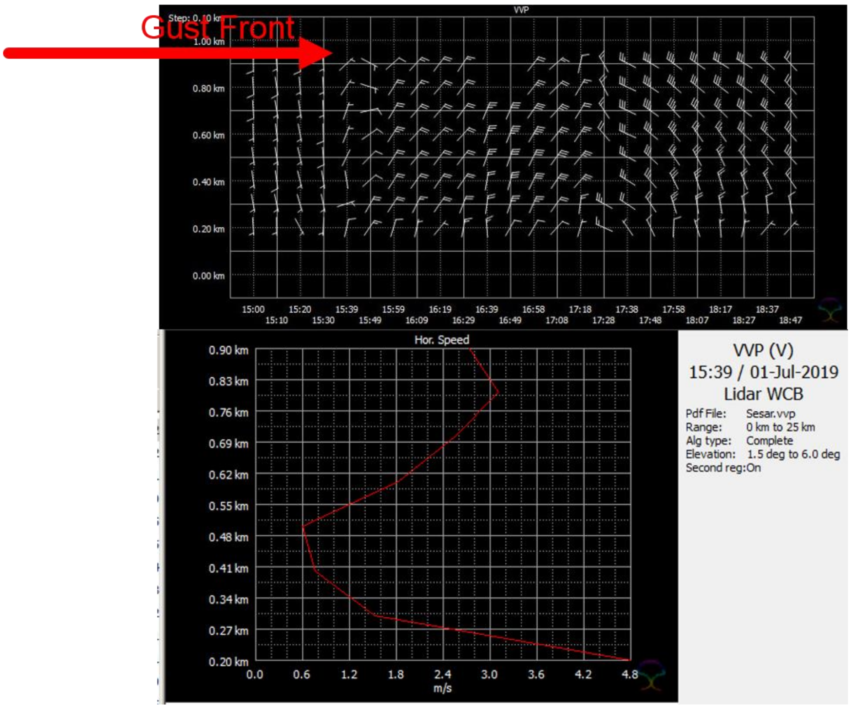


Figure 12: Time series of vertical profiles of horizontal wind for the time window of the gust front on July 1st 2019.

Some insight giving time series of the difference of lidar derived wind and Mode-S derived wind for this gust front use case are depicted in Figure 13 and Figure 14. Note especially that at 15:40, a warning of the changing wind and the unreliable forecast could have been generated on the basis of the gust front detected (compare Figure 11 and Figure 15).

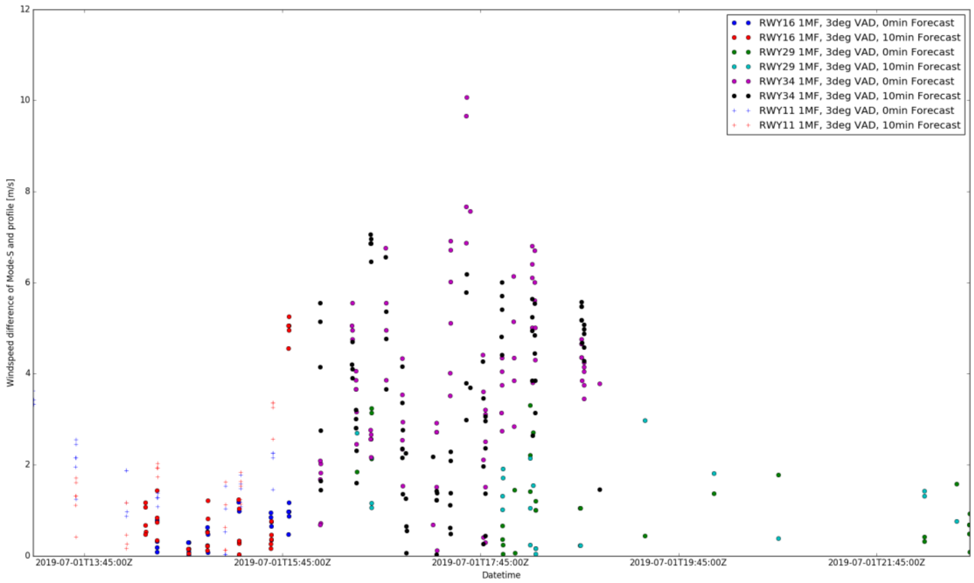


Figure 13: Absolute values of differences of Mode-S wind speed and lidar derived wind speed.

During the gust front event on 1st July for all first segments of all runway as measured and as 10 minutes forecast for the 3° path derived using VAD. Note that the rise in variation coincides precisely with the onset of the event.

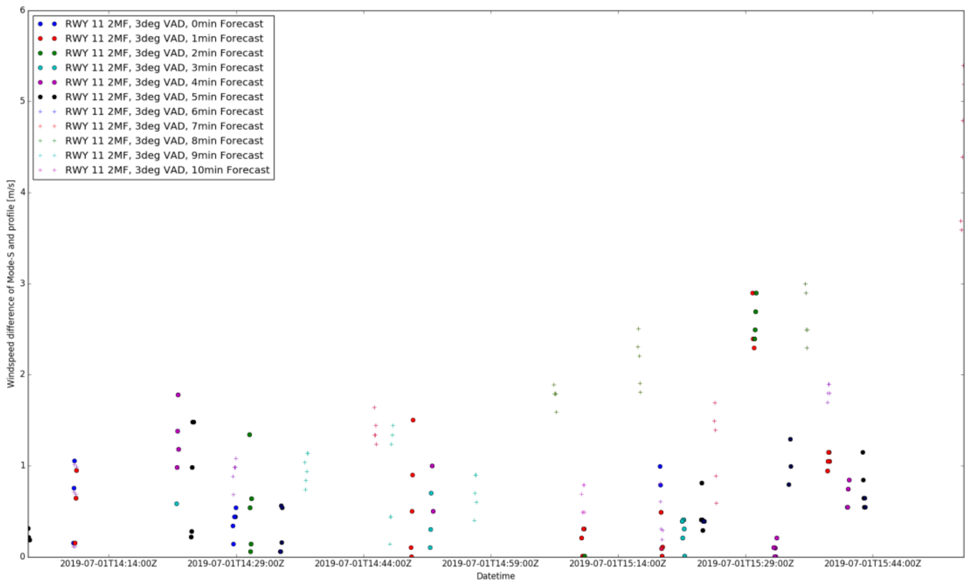


Figure 14: Absolute values of differences of Mode-S wind speed and lidar derived wind speed.

During the gust front event on 1st July for all forecast steps on runway 11, two miles forward (2MF). Note the sharp rise in the 10 minutes forecast at the end, before the runway configuration is changed.

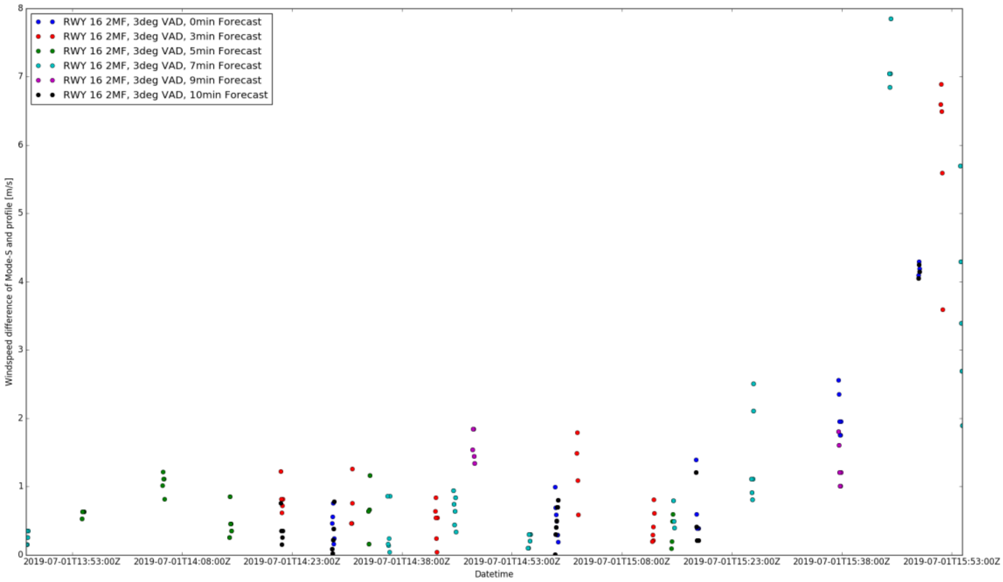


Figure 15: Absolute values of differences of Mode-S wind speed and lidar derived wind speed.

During the gust front event on 1st July for some forecast steps on runway 16, two miles forward (2MF). Note the sharp rise in the forecast at the end, before the runway configuration is changed.

CRT-18-04b-TRL6-TVALP-009.002: The glide slope wind profile can be obtained to cover the final approach area

ROSHEAR product calculates for every runway (11-29 and 16-34) and the approach/departure area respectively, up to 3NM after threshold the total wind and cross wind. Following areas could not be covered with radial velocity measurements due to blocking issues (see **¡Error! No se encuentra el origen de la referencia.**, app stand for approach, dep for departure). Note, however, that with the VAD algorithm a value for all segments is provided (see above):

- Runway 11: app3mile, app2mile, partly app1mile
- Runway 29: partly dep1mile, dep2mile, dep3mile (corresponding to runway 11)
- Runway 16: app3mile, app2mile, partly app1mile, partly dep2mile, dep3mile
- Runway 34: app3mile, partly app2mile, partly dep1mile, dep2mile, dep3mile (corresponding to runway 16)

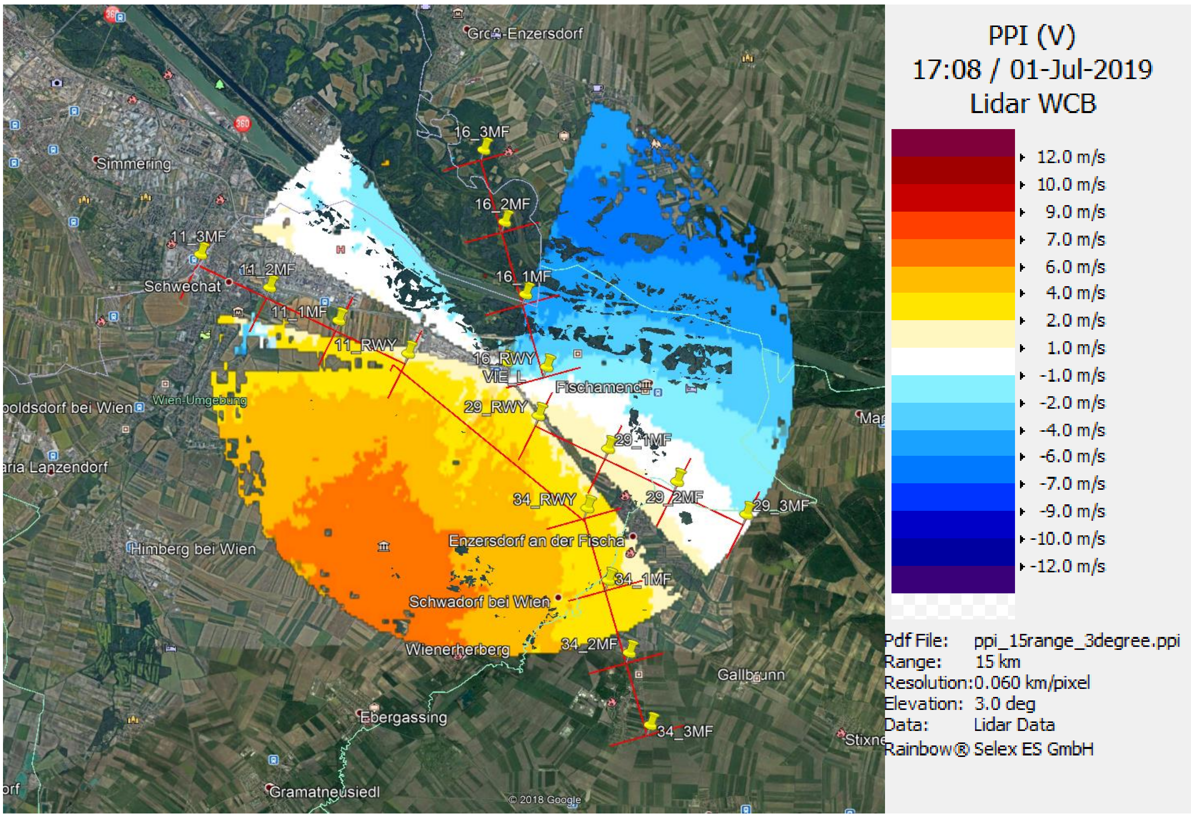


Figure 16: 15 km coverage of Lidar data around Vienna airport with three blocking areas (no data) and the approach and departure area indicated by the red lines

The three miles forward segments (1-3MF) are shown for all runway thresholds.

Blocking by buildings (e.g. the Tower) is a general constraint and depends on the possible siting of MET sensors at airports and therefore the area, which can be scanned by the instruments. Coverage of the lidar data was up to 15 km and therefore limited also the detection in the 3NM sector. Long-range lidars would help to cover also those areas more far away.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      <ele>03.000000</ele>
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      <removebw>On</removebw>
      <speckle>On</speckle>
      <wind>HWIND</wind>
   </viewparams>
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      <alt>203.000000</alt>
      <wavelen>2e-6</wavelen>
   </sensorinfo>
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```


Figure 17:Snippet of ROSHEAR output file including indication of airport (VIE), elevation (3.0), crosswind method (HWIND), runway (11), total wind (winddir, windspeed), crosswind, sector (rwycenter, app1mile).

CRT-18-04b-TRL6-TVALP-009.003: The glide slope wind profile can be provided with a high update rate of 1 min

The temporal resolution of the wind information has to be reflected in the scheduler the MET system is executing. Data acquisition, processing and provision of information have to be taken into account. In the current installation the temporal resolution changed during the 2.5 months to optimise the data acquisition on one hand and to support the plate line concept of PJ.02-01 on the other hand. Nevertheless, the update rate depends strongly on the performance of the used lidar sensor where high update rate versus data quality have to be balanced.

Therefore, the 3 degree information was available between 2-3 minutes in the highest resolution. The 6 degree data was received every 10-15 minutes. The update rate of 1 min could not be provided in this configuration. However, this depends only on the hardware and siting employed and is feasible if this is chosen otherwise. One minute is also a requirement when providing information about runway oriented shear operationally.

A.7.3 Unexpected Behaviours/Results

N/A

A.7.4 Confidence in Results of Validation Exercise #01

Level of significance/limitations of Technical Validation Exercise Results

Data have been obtained from a reliable sensor available on the market for long time. The product ROSHEAR is also operationally used in many installations worldwide to provide information about runway oriented wind shear on runway and up to 3 NM after thresholds. The product was extended to provide also total wind, wind direction and the crosswind component.

Two methods have been used to derive crosswind. The VADP (Velocity Azimuth Display Profile) method analyses velocity data from one elevation slice. Subsequently, it takes all radial velocity data for small range intervals and performs regression to a constant wind field. This is used to calculate horizontal wind speed and direction and derived crosswind for each segment but representative for the location of the sensor.

The second method is based on HWIND (Horizontal Wind) product that analyses data on a given constant height layer. The crosswind for each segment is calculated from the segment-specific horizontal wind vectors, but of constant height and not of the individual height of each segment.

Both methods have been used to derive crosswind and compared to MODE-S data for 3 and 6 degree elevation scans.

Quality of Technical Validation Exercises Results

The quality of the validation results presented above is limited by the error of the Mode-S derived wind data which is assumed to be on the order of 1.4 m/s [59]. When siting is ideal, standard deviations for the difference of total wind for Mode-S and lidar derived values on the order of 1.5 m/s are found. Large deviations occur for non-ideal siting as well as for unstable and gusty wind conditions. The onset of the latter can be prewarned in the case of a gustfront initiating a sudden change in the wind conditions.

Significance of Technical Validation Exercises Results

The results in this validation exercise have been generated from data of a three months measurement campaign under realistic conditions at Vienna airport. The siting of the instrument could have been optimized, if considered for full operational installation, but it was absolutely realistic. Therefore, the statistical and operational significances are considered high.

A.7.5 Conclusions

Conclusions on technical feasibility

It has been shown that measurement of glidepath total and crosswind by a scanning Doppler Lidar is technically feasible with quality varying with location relative to the instrument set up. An update rate of 1 minute could not be demonstrated here, but this depends only on the power of the instrument used and not on the strategy employed.

Conclusions on performance assessments

Standard deviations for most optimal locations are on the order of what can be expected from the combined precision of Mode-S wind speed and Lidar radial velocity data.

A.7.6 Recommendations

It is recommended to do a specific siting analysis for each instrument to be set up at an airport in order to optimize the quality of glide path wind data for important locations. Depending on the airport set up, it might be necessary to use more than one instrument to achieve optimal quality in all important locations. This could open up synergy effects like the possibility for Dual Doppler strategies in addition. In any way, a detailed analysis on site covering the whole local microclimate is also recommended (i.e. one year minimum, better two or three) in order to derive the precise uncertainties to be considered in the operational usage of the data for wake turbulence encounter avoidance. Additionally, the power of the instruments should be considered in order to provide update rates of 1 minute.

Appendix B Technical Validation Exercise #02 Report (EXE-18-04b-TRL2-002_LDO "METForWTS")

B.1 Summary of the Technical Validation Exercise #02 Plan

This exercise followed the description in the TVALP of project 18-04b. The service development reached only TRL2 and the service payload has been checked against the requirements of PJ.02-01.

B.2 Technical Validation Exercise #02 description and scope

This is an internal technical validation supporting PJ.02-01 where need for detailed wind information in the approach and departure paths has been identified. Wind information comprises head- and crosswind components along the respective glide/climb path. This will be used for optimising the runway and airport throughput by addressing new arrival and departure concepts **¡Error! No se encuentra el origen de la referencia.**. So far the new capability was not used in any operational exercise and the corresponding service is not finally developed. MEGA modelling has been done as well as the payload definition (EA models). In this exercise, we check the payload against the design requirements written in PJ.18-04b TS [39] which are based on PJ.02-01 SPR/INTEROP OSED **¡Error! No se encuentra el origen de la referencia.**.

B.3 Summary of Exercise #02 Technical Validation Objectives and success criteria

The objective is to validate that the payload of the service METForWTS designed fit for purpose. This is only a design exercise checking the content of the message with no impact on any further technological system or operational concept.

Identifier	Success Criterion
CRT-18-04b-TRL2-TVALP-010.001	Review of design of the glide slope wind profile service is done and shows that the service complies with the requirements.

The respective requirements associated with this exercise can be found in the TS of PJ18-04b [39] in sections 4.2.2 (Information and Alerting), 4.2.3 (Measurements) and 4.2.4 (Services):

- REQ-18-04b-TS-CC31.0020: Glidepath Wind Profile
- REQ-18-04b-TS-CC31.0030: Glidepath Wind Profile Forecast
- REQ-18-04b-TS-CC42.0030: Very short term forecast wind field near the airport
- REQ-18-04b-TS-CC42.0040: Glidepath real time wind monitoring
- REQ-18-04b-TS-IS1.0020: Glide slope wind profile service (METForWTS)

It has to be noted that in the beginning PJ.02-01 mostly included requirements derived from SESAR1 projects and other research projects (CREDOS). Those have been the basis on which the model and service have been designed because nothing else was available as input. Therefore, in the EA models the payload messages are linked to these "old" requirements. In the final OSED [41] all these requirements have been reworked, new text and ID added. For traceability reasons, the following excel table (Table 8) is included. It provides a short summary what shall be included in the METForWTS service and therefore the above five requirements have been formulated. Additionally, requirements from arrival and departure concepts are included: in column A and C (grey, italic), old requirements from first versions of OSED, in column B and D requirements from latest OSED document **¡Error! No se encuentra el origen de la referencia.**.

Table 8: Mapping of later and earlier requirements on which the payload design had been based

METForWTS_REQ.xls
x

Although the requirements have been changed, the content is more or less the same. Therefore, the METForWTS service design is deemed still valid.

B.4 Summary of Technical Validation Exercise #02 Validation scenarios

No reference scenario is applicable since the exercise deals with the payload of the service. It is checked that the payload includes wind information of cross- and headwind components along the glidepath, METForWTS, as specified. Also current, nowcast and forecast values are included.

B.5 Summary Technical Validation Exercise #02 Assumptions

N/A

B.6 Deviation from the planned activities

N/A

B.7 Technical Validation Exercise #02 Validation Results

B.7.1 Summary of Technical Validation Exercise #02 Results

Technical Validation Exercise #02 Validation Objective ID	Technical Validation Exercise #02 Validation Objective Title	Technical Validation Exercise #02 Success Criterion ID	Technical Validation Exercise #02 Success Criterion	Technical Validation Exercise #02 Results	Technical Validation Exercise #02 Validation Objective Status

OBJ-18-04b-TRL2-TVALP-010	Glideslope wind profile service	CRT-18-04b-TRL2-TVALP-010.001	Review of design of the glide slope wind profile service is done and shows that the service complies with the requirements.	Content according to the payload schema was checked and complies with the requirements	OK

Table 9: Technical Validation Results Exercise #02

Results on technical feasibility

N/A for the service payload.

Results per KPA

N/A. For addressing KPAs please refer to [41].

B.7.2 Analysis of Exercise #02 Results per Technical Validation objective

OBJ-18-04b-TRL6-TVALP-010 Results

The service has been designed according to received requirements and reviewed with respect to these in this exercise. The service payload is considered compliant. The results are satisfying and fulfil the requirements.

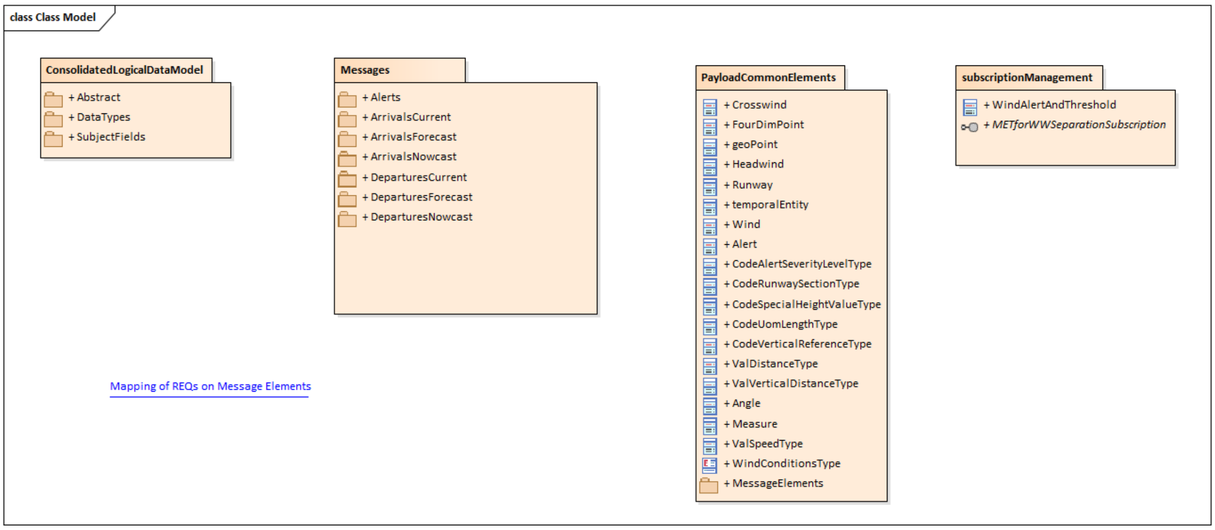


Figure 18: Class Model of METForWTS service. Mostly derived from AIRM library.

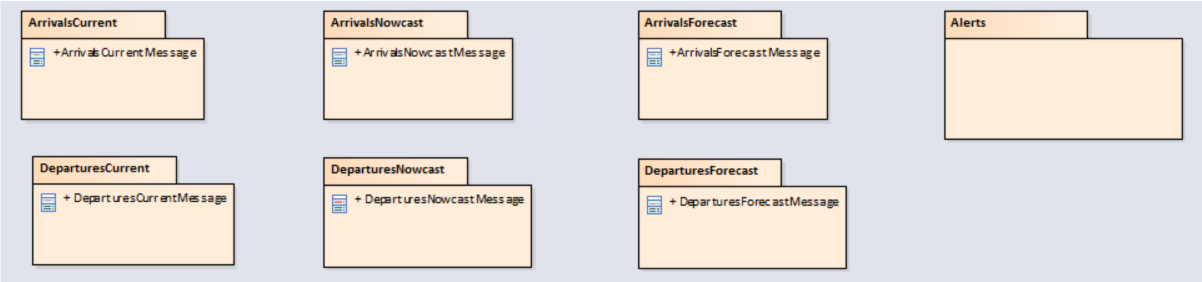


Figure 19: Payload messages of the METForWTS service

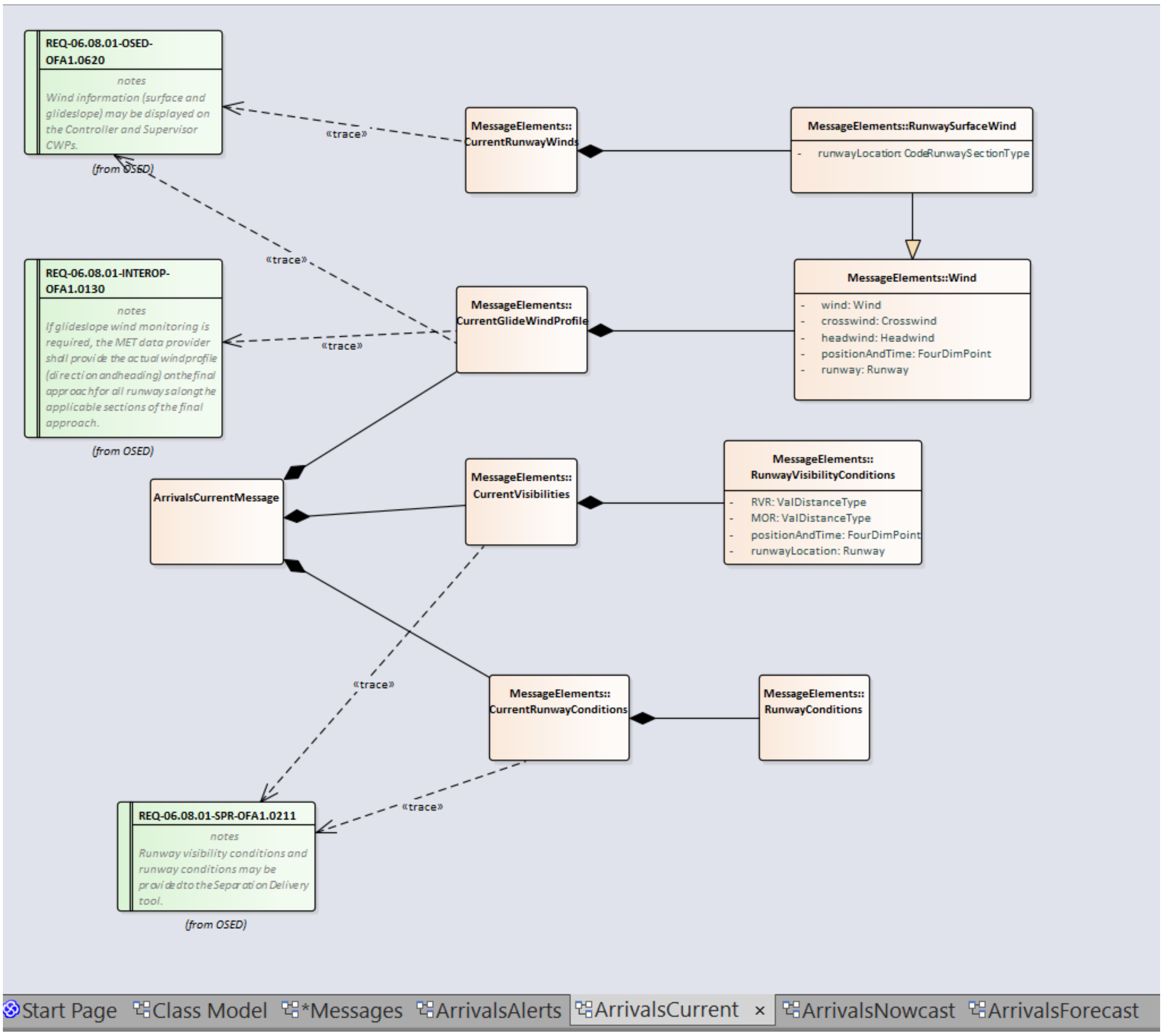


Figure 20: Class ArrivalsCurrent with the message elements and the link to OSED Requirements.

In addition, a presentation including all the message payloads and the general design of the METForWTS service was sent to PJ.02-01 representatives for review. During a webex, a draft design was discussed and based on PJ02-01's feedback, the design has been changed to the state that has been reviewed in this exercise. The presentation with the final concept is included below. Based on this model the validation has been conducted.

dataModel_METfor
WWSeparation.pptx

N/A

B.7.3 Confidence in Results of Validation Exercise 1

Level of significance/limitations of Technical Validation Exercise Results

N/A since only check of service payload against schema and requirements.

Quality of Technical Validation Exercises Results

N/A since only check of service payload against schema and requirements.

Significance of Technical Validation Exercises Results

N/A since only check of service payload against schema and requirements.

B.7.4 Conclusions

The service complies with the requirements. Design was done via EA models and in MEGA and reached therefore TRL 2.

Conclusions on technical feasibility

N/A

Conclusions on performance assessments

N/A

B.7.5 Recommendations

Service is very useful for glidepath wind monitoring. The service should be further developed and tested with real data and provided to operational customers during a shadow mode validation exercise.

Appendix C Technical Validation Exercise #03 Report (EXE-18-04b-TRL4-001_CCL “Bora wind detection”)

C.1 Summary of the Technical Validation Exercise #03 Plan

Prerequisite for the Validation Exercise was the measurement campaign at Dubrovnik airport, which was conducted under umbrella of PJ.04-02’s exercise PJ.04-02.V2.04 during winter 2017/2018. The general idea of campaign was to measure spatio-temporal structure of the mean Bora airflow and turbulence in the immediate vicinity of Dubrovnik airport using Scanning Doppler Lidar.

Preliminary actions for the Validation Exercise itself were a series of workshops (internal, F2F and e-mail discussions) with experts from LEONARDO Germany GmbH and CCL/COOPANS, during which experts from both sides worked together on the analysis of data recorded by the Scanning Doppler Lidar during the measurement campaign and preparing the material for Validation exercise. The aim was to validate the suitability of the Lidar scanning patterns used to monitor the risk stemming from Bora winds. These actions started in November 2018 and Validation Exercise itself was planned and successfully finished at the workshop at the end of March 2019.

C.2 Technical Validation Exercise description and scope

This activity addressed the dependency with PJ04-02 where a need for detection of the Bora wind for Total Airport Management has been stated. In the scope of PJ.04-02, Val Exe PJ04.02-V2.04 [46], a measurement campaign using a Scanning Doppler Wind Lidar has been performed at Dubrovnik Airport during the winter months 2017/2018. This Validation Exercise was dedicated to analyse the data collected in this campaign and to validate that the scanning Doppler Lidar is a suitable instrument for the identification of hazards caused by Bora wind and to gain insight into the different regimes of the Bora phenomenon. Of special interest were crosswinds with mean speed above 25KT and gusts above 35KT, and also strong horizontal and vertical wind shear, which have significant impact on traffic and reduce airport operations.

C.3 Summary of Validation Exercise Technical Validation Objectives and success criteria

[OBJ]

Identifier	OBJ-18-04b-TRL4-TVALP-006
Objective	To validate that dangerous runway crosswinds (Bora wind), and phenomena associated with Bora, in the vicinity of Dubrovnik airport, can be observed by Doppler Wind Lidar.
Title	Bora Wind Measurement
Category	<technical feasibility>
Key environment conditions	Adverse wind conditions
TRL Phase	TRL4

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC42.0010

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL4-TVALP-006.001	Lidar data confirms north-east wind (runway crosswind) at lowest levels and approach area.
CRT-18-04b-TRL4-TVALP-006.002	Height of Bora wind layer can be detected from lidar images.
CRT-18-04b-TRL4-TVALP-006.003	Heterogeneous wind flows, which could represent turbulent areas, can be detected from lidar images.

[OBJ]

Identifier	OBJ-18-04b-TRL4-TVALP-007
Objective	To validate that dangerous wind variations (wind shear) in Bora wind in the vicinity of Dubrovnik airport can be observed by Doppler Wind Lidar
Title	Bora Wind Shear Measurement
Category	<technical feasibility>
Key environment conditions	Adverse wind conditions
TRL Phase	TRL4

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC42.0020

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL4-TVALP-007.001	Wind shear in approach to the Dubrovnik airport can be detected from lidar images.

CRT-18-04b-TRL4-TVALP-007.002	Wind rotors and wind shear in vicinity of Dubrovnik airport can be detected from lidar RHI (vertical) and PPI (horizontal) images.

C.4 Summary of Technical Validation Exercise #03 Validation scenarios

Reference scenario: Standard MET messages like METAR and TAF served as a baseline for this exercise, but a reference scenario was not applicable because the exercise was only an analysis of the lidar data and how they reveal important features of Bora episodes.

Solution scenario: The Lidar measurements make features of the Bora phenomenon visible that have not been seen to date. Especially terrain induced wind shear and turbulence are very localised and not captured by standard sensors.

C.5 Summary Technical Validation Exercise #03 Assumptions

N/A

C.6 Deviation from the planned activities

N/A

C.7 Technical Validation Exercise #03 Validation Results

C.7.1 Summary of Technical Validation Exercise #03 Results

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
OBJ-18-04b-TRL4-TVALP-006	Bora Wind Measurement	CRT-18-04b-TRL4-TVALP-006.001	Lidar data confirms north-east wind (runway crosswind) at lowest levels and approach area.	With average of 4.88/5, validation participants expressed agreement via dedicated question in the questionnaire	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
		CRT-18-04b-TRL4-TVALP-006.002	Height of Bora wind layer can be detected from lidar images.	With average of 4.31/5, validation participants expressed agreement via dedicated question in the questionnaire	OK
		CRT-18-04b-TRL4-TVALP-006.003	Heterogeneous wind flows, which could represent turbulent areas, can be detected from lidar images.	With average of 4.31/5, validation participants expressed agreement via dedicated question in the questionnaire	OK
OBJ-18-04b-TRL4-TVALP-007	Bora Wind Shear Measurement	CRT-18-04b-TRL4-TVALP-007.001	Wind shear in approach to the Dubrovnik airport can be detected from lidar images.	With average of 4.63/5, validation participants expressed agreement via dedicated question in the questionnaire	OK
		CRT-18-04b-TRL4-TVALP-007.002	Wind rotors and wind shear in vicinity of Dubrovnik airport can be	With average of 4.25/5, validation participants expressed agreement via	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
			detected from lidar RHI (vertical) and PPI (horizontal) images.	dedicated question in the questionnaire	

Table 10: Technical Validation Results Exercise EXE-18-04b-TRL4-001_CCL

Results on technical feasibility

N/A

Results per KPA

N/A

C.7.2 Analysis of Exercise #03 Results per Technical Validation objective

After Bora measurement campaign, in preparation of the material for the validation exercise, data was thoroughly analysed by MET experts and lidar images were prepared for every question in the validation questionnaire, having in mind objective of the exercise and to instigate useful discussion among experts.

Validation results are based on operational weather forecasters' and MET experts' judgement, who are the people with vast knowledge and practical experience in analysing the data and deciding on its usefulness in possible future operational use. Validation exercise participants answered set of questions to identify and get answers whether the expected benefits could be achieved. The following methodology was chosen for the evaluation of results:

- Each *Criterion for assessment* could be assessed using values from 1 to 5 by responders (where the full acceptance with the provided statement is represented by the value 5)
- For *Criterion for assessment* to be successfully validated, it was agreed by the experts, that the average value had to reach at least 3.75/5 from responders, which represents 75% of the objective fulfilment.

For each validation objective, the results were transformed into graphs.

In addition to the answers to the questionnaire, number of interesting comments from participants were collected, which provided material for better understanding of participants' answers and presented ground for possible further analysis of data and ideas for possible future use of lidar instrument.

OBJ-18-04b-TRL4-TVALP-006 Results

The aim of validation objective OBJ-18-04b-TRL4-TVALP-006 (Bora wind measurement) is to validate that dangerous runway crosswinds (Bora wind), and phenomena associated with Bora, in the vicinity of Dubrovnik airport, can be observed by Doppler Wind Lidar. The success criteria evaluated in this validation objective has been:

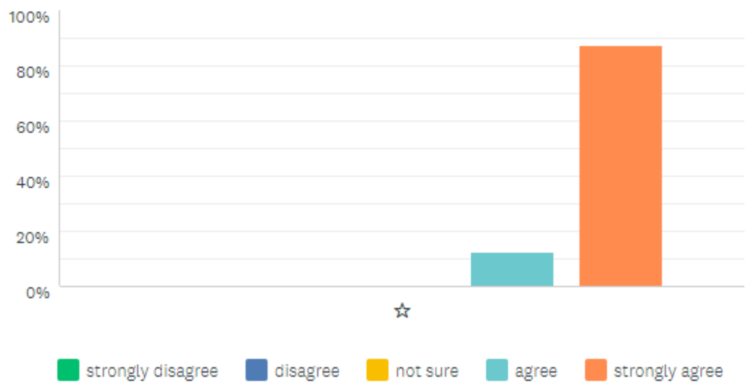
CRT-18-04b-TRL4-TVALP-006.001

For this success criterion, the following hypothesis was postulated: "*Lidar data confirms north-east wind (runway crosswind) at lowest levels and approach area.*"

This success criterion has been fulfilled in the following way:

Validation exercise participants (operational weather forecasters and MET experts) involved in the validation exercise were shown prepared material (lidar PPI images) and then they were presented with hypothesis and assigned the number from 1 (strongly disagree) to 5 (strongly agree) with optional textual description of answer. Criterion for assessment to be successfully validated, the average value had to reach at least 3.75/5 from responders, which represents 75% of the objective´s fulfilment.

Question/hypothesis 1: *Lidar data confirms north-east wind (runway crosswind) at lowest levels and approach area.*



	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	0.00% 0	12.50% 2	87.50% 14	16	4.88

Figure 21: Question/hypothesis 1 for OBJ-18-04b-TRL4-TVALP-006 evaluation

Average result of 4.88/5 clearly showed that validation participants strongly agree that prevalence of wind speed and direction, not only on runway, but also in vicinity of Dubrovnik airport, can be determined from lidar data. In present day, weather forecasters have only two operational anemometers on both runway thresholds and they agreed that knowing wind speed and direction in proximity of the airport would be very useful and could improve weather forecasts, such as, and not limited to, ICAO products, TAF and TREND.

There was one very important additional point which added to the deeper understanding of the problematics. It was indicated that the siting of lidar is extremely important for getting good and representative data from the measurements and during discussion around the topic participants agreed that in this case siting was very good because it managed to catch most of the important areas around Dubrovnik airport.

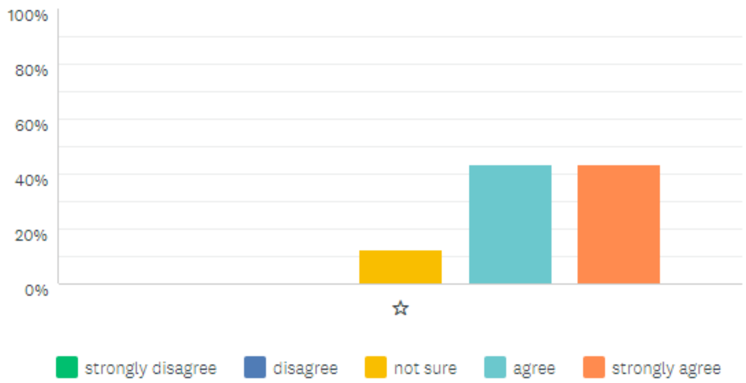
CRT-18-04b-TRL4-TVALP-006.002

For this success criterion, the following hypothesis was postulated: "*Height of Bora wind layer can be detected from lidar images.*"

This success criterion has been fulfilled in the following way:

Validation exercise participants (operational weather forecasters and MET experts) involved in the validation exercise were shown prepared material (lidar RHI images) and then they were presented with hypothesis and assigned the number from 1 (strongly disagree) to 5 (strongly agree) with optional textual description of answer. Criterion for assessment to be successfully validated, the average value had to reach at least 3.75/5 from responders, which represents 75% of the objective´s fulfilment.

Question/hypothesis 2: *Height of Bora wind layer can be detected from lidar images.*



	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	12.50% 2	43.75% 7	43.75% 7	16	4.31

Figure 22: Question/hypothesis 2 for OBJ-18-04b-TRL4-TVALP-006 evaluation

Average result of 4.31/5 showed that validation participants agree that, in most cases, lidar RHI images could be beneficial in determining height of Bora layer, i.e. height of layer in which Bora wind is strong and prevalent. That information could further help in determining which Bora type is prevalent in vicinity of Dubrovnik airport (Bora type classification is topic of other PJ.18-04b CCL/COOPANS' validation exercise).

Additional discussion evolved around the topic if lidar data could also show data in higher troposphere, which could additionally help in determining Bora type more easily. Participants concluded that in most cases, even if lidar data don't reach that high into troposphere, gathered data could nevertheless indicate and give valuable additional help in determining Bora type.

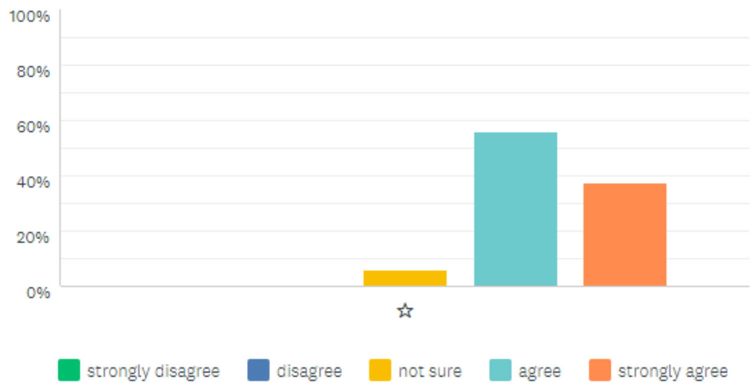
CRT-18-04b-TRL4-TVALP-006.003

For this success criterion, the following hypothesis was postulated: "*Heterogeneous wind flows, which could represent turbulent areas, can be detected from lidar images.*"

This success criterion has been fulfilled in the following way:

Validation exercise participants (operational weather forecasters and MET experts) involved in the validation exercise were shown prepared material (lidar PPI images) and then they were presented with hypothesis and assigned the number from 1 (strongly disagree) to 5 (strongly agree) with optional textual description of answer. Criterion for assessment to be successfully validated, the average value had to reach at least 3.75/5 from responders, which represents 75% of the objective´s fulfilment.

Question/hypothesis 3: *Heterogeneous wind flows, which could represent turbulent areas, can be detected from lidar images.*



	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	6.25% 1	56.25% 9	37.50% 6	16	4.31

Figure 23: Question/hypothesis 3 for OBJ-18-04b-TRL4-TVALP-006 evaluation

Average result of 4.31/5 indicate that validation participants agree that turbulent areas in vicinity of Dubrovnik airport can be detected from lidar. During following discussion, the reason for not reaching even higher average results was found to lie down in the fact that validation participants needed more time and additional training for use of lidar data.

OBJ-18-04b-TRL4-TVALP-007 Results

The aim of validation objective OBJ-18-04b-TRL4-TVALP-007 (Bora wind shear measurement) is to validate that dangerous wind variations (wind shear) in Bora wind in the vicinity of Dubrovnik airport can be observed by Doppler Wind Lidar. The success criteria evaluated in this validation objective has been:

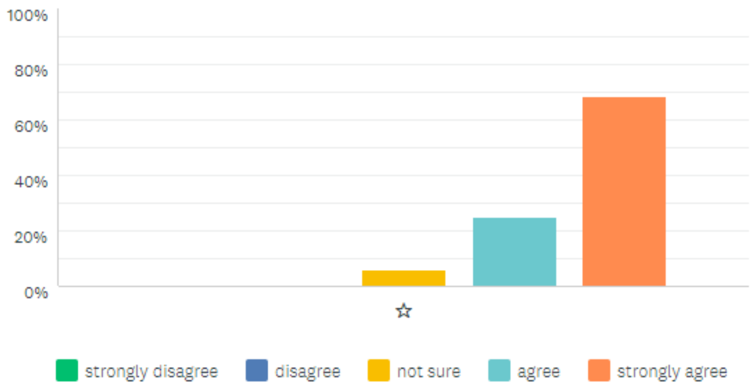
CRT-18-04b-TRL4-TVALP-007.001

For this success criterion, the following hypothesis was postulated: “*Wind shear in approach to the Dubrovnik airport can be detected from lidar images.*”

This success criterion has been fulfilled in the following way:

Validation exercise participants (operational weather forecasters and MET experts) involved in the validation exercise were shown prepared material (lidar PPI images) and then they were presented with hypothesis and assigned the number from 1 (strongly disagree) to 5 (strongly agree) with optional textual description of answer. Criterion for assessment to be successfully validated, the average value had to reach at least 3.75/5 from responders, which represents 75% of the objective´s fulfilment.

Question/hypothesis 1: *Wind shear in approach to the Dubrovnik airport can be detected from lidar images.*



	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	6.25% 1	25.00% 4	68.75% 11	16	4.63

Figure 24: Question/hypothesis 1 for OBJ-18-04b-TRL4-TVALP-007 evaluation

Average result of 4.63/5 indicate that validation participants strongly agree that areas affected by strong wind shear in approach to Dubrovnik airport can be detected from lidar data. It was concluded that it is extremely important to have whole approach area covered by lidar data, as airport and its runway are positioned so that whole approach area is strongly affected by Bora wind and associated phenomena during Bora episodes and often result in missed approach or even rerouting scheduled airplanes to alternate airports.

Discussion emerged around comment that only from lidar PPI images is hard to be completely sure of existence of wind shear. What is very easy and clear to detect are different wind flows and for the more detailed analysis it would be of great help to have either 3D display or "along the approach path" display with additional lidar instrument. Validation participants agreed that of course funding has to be taken into account and that they were very satisfied with results which were obtained from existing lidar instrument and its siting relative to Dubrovnik airport.

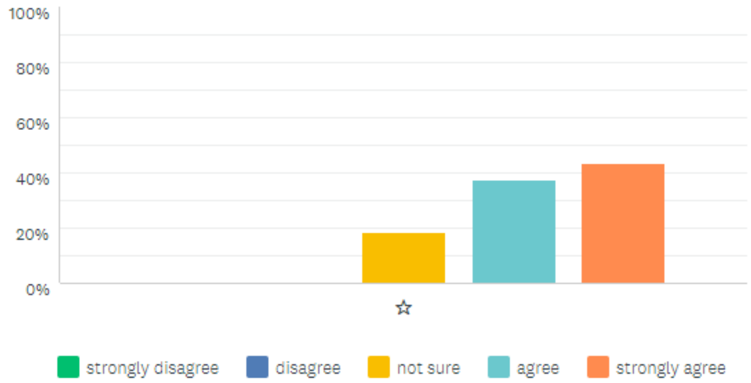
CRT-18-04b-TRL4-TVALP-007.002

For this success criterion, the following hypothesis was postulated: "*Wind rotors and wind shear in vicinity of Dubrovnik airport can be detected from lidar RHI (vertical) and PPI (horizontal) images.*"

This success criterion has been fulfilled in the following way:

Validation exercise participants (operational weather forecasters and MET experts) involved in the validation exercise were shown prepared material (lidar PPI and RHI images) and then they were presented with hypothesis and assigned the number from 1 (strongly disagree) to 5 (strongly agree) with optional textual description of answer. Criterion for assessment to be successfully validated, the average value had to reach at least 3.75/5 from responders, which represents 75% of the objective´s fulfilment.

Question/hypothesis 2: *Wind rotors and wind shear in vicinity of Dubrovnik airport can be detected from lidar RHI (vertical) and PPI (horizontal) images.*



	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	18.75% 3	37.50% 6	43.75% 7	16	4.25

Figure 25: Question/hypothesis 2 for OBJ-18-04b-TRL4-TVALP-007 evaluation

Average result of 4.25/5 indicate that validation participants agree with given hypothesis that areas affected by strong wind shear and vertical wind rotors in vicinity of Dubrovnik airport can be detected from lidar data. Additionally, RHI images would be useful for forecaster to have greater awareness of what phenomena are existing in vicinity of Dubrovnik airport.

Additional questions and comments

As a global comment to Bora detection validation exercise, it was deemed important to emphasize one repeated comment during discussions, and that was that validation participants would need more time and training to completely familiarize with lidar images, if they are to use that data effectively in their operational use in the future (e.g. distinguishing wind rotors from wind shear). As these were first lidar measurements ever done in Croatia, this comment was expected by validation exercise leaders so, in addition to question/hypothesis directly oriented to validation exercise objective, few additional ones were added to questionnaire with the aim of getting useful operational feedback from operational weather forecasters around topic of possible inclusion of lidar into operational use.

One question postulated like *''Would you feel more confident in giving pilot briefing regarding possibility of landing during Bora episodes, if you would have operational lidar images? (e.g. there are approaching flights and the wind speed is near exceeding the threshold for safe landing)''* received average answer of 4.27/5, and another postulated like *''Do you think it would provide additional benefit to you in raising situational awareness and improving forecasts for LDDU if you would have lidar in operational use?''* received average answer of 4.87/5. Both these results clearly show that operational weather forecasters would extremely appreciate help that could operational lidar offer with Bora wind forecasts, because of their awareness that this combination of airport runway configuration and Bora wind direction and strength is almost unique and can have, and is having, adverse impact to traffic operations.

Study of turbulence

As parallel action to validation exercise itself, Faculty of Science from Zagreb has done study of correlations between measured turbulence parameters and output fields of numerical weather prediction models.

Main idea behind study was that wind speed measurements at LDDU are available only at two points, at the runway thresholds 12 and 30, at the height of 10m above the ground. In the conditions of bora flows, wind speeds at these two points are often significantly different. These differences indicate to an additional problem of the wind shear in the atmospheric surface layer (ASL).

In the conditions of strong bora flows at the LDDU, there is a great uncertainty in the air traffic flow. As these kinds of situations represent a potential safety hazard, it is required to define suitable/proper measures for the decision-making system in order to make it easier for all air traffic participants in making decision whether the landing at the LDDU will take place or not.

In the process of forecasting of bora flows, forecasters at the LDDU (or allocated ones), among other materials, use the outputs of the numerical weather prediction model ALADIN in the forms of so-called pseudo-temps. During years of experience, they developed different empirical methods for predicting bora gusts using data of the mean horizontal wind speed predicted by ALADIN. However, as the bora gusts are closely related to its turbulence (Belušić et al. 2006; Večenaj et al. 2010b), a question that naturally arises is how the variables/parameters of turbulence simulated by ALADIN are related to those that really occurred at the runway and its nearby vicinity. In order to study this, it is necessary to measure those variables/parameters in a time period as long as possible in which multiple bora events will occur and compare them with simulated ones.

Within this project, an experiment was designed in which the wind speed was measured using instruments for measuring air turbulence, mounted on the 10-m meteorological tower at the two heights above the ground (3 and 10 m) in the winter period from the end of 2017 till the end of the first quarter of 2018, simultaneously to lidar measurements.

Detailed results and conclusions are written in [58].

C.7.3 Unexpected Behaviours/Results

There was no unexpected behaviours/results in this validation exercise.

C.7.4 Confidence in Results of Validation Exercise #03

Level of significance/limitations of Technical Validation Exercise Results

Results obtained in technical validation exercise EXE-18-04b-TRL4-001_CCL are representative because validation participants were operational forecasters and MET experts from CCL/COOPANS which have vast theoretical and practical operational knowledge about Bora wind problematics.

High average results obtained in the questionnaire show that validation participants are very confident about results obtained from lidar images and its usefulness in their operational work.

Quality of Technical Validation Exercises Results

During technical validation exercise all operational forecasters and MET experts from CCL/COOPANS, with vast theoretical and practical knowledge of Bora wind problematics, were present and were active during questionnaire and following discussion, and that lidar scans of Bora episodes taken for the questionnaire were selected with great care and having in mind their overall significance and representativeness, quality of results are considered to be very high.

Significance of Technical Validation Exercises Results

Having in mind number of validation participants and their knowledge and number and overall duration and representativeness of chosen lidar scans during Bora episodes, results obtained have both statistical and operational significance.

C.7.5 Conclusions

Two objectives were defined for this validation exercise.

To successfully fulfil OBJ-18-04b-TRL4-TVALP-006 *''To validate that dangerous runway crosswinds (Bora wind), and phenomena associated with Bora, in the vicinity of Dubrovnik airport, can be observed by Doppler Wind Lidar.''* three success criteria had to be fulfilled.

Average result of 4.88/5 clearly showed that validation participants strongly agree that prevalence of wind speed and direction, not only on runway, but also in vicinity of Dubrovnik airport, can be determined from lidar data. In present day, weather forecasters have only two operational anemometers on both runway thresholds and they agreed that knowing wind speed and direction in proximity of the airport would be very useful and could improve weather forecasts, such as, and not limited to, ICAO products, TAF and TREND.

Average result of 4.31/5 for CRT-18-04b-TRL4-TVALP-006.002 showed that validation participants agree that, in most cases, lidar RHI images could be beneficial in determining height of Bora layer, i.e. height of layer in which Bora wind is strong and prevalent.

Average result of 4.31/5 for CRT-18-04b-TRL4-TVALP-006.003 indicate that validation participants agree that turbulent areas in vicinity of Dubrovnik airport can be detected from lidar.

To successfully fulfil second objective of this validation exercise, OBJ-18-04b-TRL4-TVALP-007 *''To validate that dangerous wind variations (wind shear) in Bora wind in the vicinity of Dubrovnik airport can be observed by Doppler Wind Lidar''*, three success criteria had to be fulfilled.

Average result of 4.63/5 for CRT-18-04b-TRL4-TVALP-007.001 indicate that validation participants strongly agree that areas affected by strong wind shear in approach to Dubrovnik airport can be detected from lidar data. Two additional conclusions were made regarding this success criterion. Firstly, it was concluded that it is extremely important to have whole approach area covered by lidar data, as airport and its runway are positioned so that whole approach area is strongly affected by Bora wind and associated phenomena during Bora episodes and often result in missed approach or even rerouting scheduled airplanes to alternate airports. Furthermore, it was concluded that to be completely sure of existence of wind shear along PPI images, there should be also 3D display or ''along the approach path'' display with additional lidar instrument.

Average result of 4.25/5 for CRT-18-04b-TRL4-TVALP-007.002 indicate that validation participants agree with given hypothesis that areas affected by strong wind shear and vertical wind rotors in vicinity of Dubrovnik airport can be detected from lidar data.

It was indicated that the siting of lidar is extremely important for getting good and representative data from the measurements and during discussion around the topic participants agreed that in this case siting was very good because it managed to catch most of the important areas around Dubrovnik airport.

Following discussion showed that main problem for fully understanding lidar images to validation participants was lack of time needed to familiarize with lidar images, especially to use for such details like distinguishing wind rotors from wind shear, but participants agreed that with additional training, lidar images would provide great help for distinguishing these phenomena and for use in operational work overall.

Answers to two additional questions (*''Would you feel more confident in giving pilot briefing regarding possibility of landing during Bora episodes, if you would have operational lidar images? (e.g. there are approaching flights and the wind speed is near exceeding the threshold for safe landing)''* received average answer of 4.27/5, and another postulated like *''Do you think it would provide additional benefit to you in raising situational awareness and improving forecasts for LDDU if you would have lidar in operational use?''* received average answer of 4.87/5.) clearly show that operational weather forecasters would extremely appreciate help that could operational lidar offer with Bora wind forecasts, because of their awareness that this combination of airport runway configuration and Bora wind direction and strength is almost unique and can have, and is having, adverse impact to traffic operations.

Conclusions on technical feasibility

N/A

Conclusions on performance assessments

N/A

C.7.6 Recommendations

1) additional training time for validators to familiarize with new images, materials prior to validation exercise

Following repeated comment during validation exercise was that validators lacked time to completely familiarize with lidar images if they are to use that data effectively in their operational use in the future, it is recommended that for future validation exercises of this type, there is additional time scheduled or additional material prepared for validators to get to understand lidar images better.

2) Inclusion of 3D display or ‘’along the approach path’’ display

From lidar PPI images alone it is hard to be completely sure of existence of wind shear. For the more detailed analysis it would be of great help to have either 3D display or "along the approach path" display with additional lidar instrument.

Appendix D Technical Validation Exercise #04 Report (EXE-18-04b-TRL4-002_CCL "Bora wind classification algorithm")

D.1 Summary of the Technical Validation Exercise #04 Plan

Preliminary actions for the Validation Exercise itself were:

- development of Bora wind classification algorithm, which has been developed by CCL MET experts with the aim of understanding wind speed and direction variances with respect to the risk of their development on short time scales during Bora episodes
- pre-recorded anemometer data of the 10 m winds at Runway 12 of Dubrovnik airport was used as input to the classification algorithm
- measurement campaign at Dubrovnik airport, which was conducted under umbrella of PJ.04-02's exercise PJ.04-02.V2.04 during winter 2017/2018. The general idea of campaign was to measure spatio-temporal structure of the mean Bora airflow and turbulence in the immediate vicinity of Dubrovnik airport using Scanning Doppler Lidar

The aim of the exercise was to validate that obtained classification results are acceptable from MET side and can give additional value to the future user. The classification results were assessed by expert assessment given Scanning Lidar and mesoscale NWP model (ALADIN) data. Exercise itself was planned and successfully finished at the beginning of June 2019.

D.2 Technical Validation Exercise description and scope

This activity addresses the dependency with PJ04-02 where need for a classification of Bora episodes has been identified as key for understanding wind speed and direction variances with respect to the risk of their development on short time scales. In the scope of PJ.04-02, Val Exe PJ04.02-V2.04 [46], a measurement campaign using a Scanning Doppler Wind Lidar has been performed at Dubrovnik Airport during the winter months 2017/2018. This exercise is dedicated to validate that the Bora wind classification algorithm can be performed on available infrastructure at Dubrovnik airport, that is 10m wind anemometer measurements and that it provides correct classification results.

D.3 Summary of Validation Exercise Technical Validation Objectives and success criteria

[OBJ]

Identifier	OBJ-18-04b-TRL4-TVALP-008
Objective	To validate that the Bora wind classification algorithm can be run on measurements derived from available MET infrastructure and provide correct classification results.
Title	Bora Wind Classification Algorithm

Category	<technical feasibility>
Key environment conditions	Adverse wind conditions
TRL Phase	TRL4

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC31.0010
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC31.0011

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL4-TVALP-008.001	Characteristics taken from 10 m anemometer wind measurements can be used for Bora wind classification algorithm.
CRT-18-04b-TRL4-TVALP-008.002	Characteristics taken from 10 m anemometer wind measurements can be used to classify different Bora types.
CRT-18-04b-TRL4-TVALP-008.003	Bora classification algorithm correctly recognizes start and end of Bora episodes.

D.4 Summary of Technical Validation Exercise #04 Validation scenarios

Reference Scenario: Standard MET messages like METAR, TREND, TAF and AD WRNG serve as a baseline for this exercise, but a reference scenario is not applicable to this exercise.

Solution Scenario: Bora classification algorithm has been developed and run on 10m anemometer measurements (available infrastructure at Dubrovnik airport) with the aim to validate that obtained classification results are acceptable from MET side and can give additional value to the future user.

Algorithm of classification of Bora types based on observations of the wind from the operational anemometer:

Steps:

1) Criteria for one METAR report

a) unclassified (suspicious) report for Bora (wind speed at least 6KT, mean wind direction from 330 to 080)

b) nocturnal gap flow – average wind speed <20KT, without gusts, average direction between 360° and 050°; occurs only between 18-06UTC

c) deep Bora - average wind speed <25KT, gusts present, wind direction from 300° to 040° or VRB

d) Bora - average wind speed more than 20KT, gusts present, average wind direction between 360° and 050°

2) Time filter of individual events in time series of every Bora type (deep Bora, Bora, nocturnal gap flow, unclassified, not bora) with function MofN (at least 2 events in last 5 METAR reports)

3) Order of final Bora type time series: deep Bora, Bora, nocturnal gap flow, unclassified, not Bora

D.5 Summary Technical Validation Exercise #04 Assumptions

N/A

D.6 Deviation from the planned activities

N/A

D.7 Technical Validation Exercise #04 Validation Results

D.7.1 Summary of Technical Validation Exercise #04 Results

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
OBJ-18-04b-TRL4-TVALP-008	Bora Wind Classification Algorithm	CRT-18-04b-TRL4-TVALP-008.001	Characteristics taken from 10m anemometer wind measurements can be used for Bora wind classification algorithm.	Average result of 4.23/5 showed that validation participants agree that classification algorithm with data from 10m anemometer measurement recognizes Bora episodes.	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
		CRT-18-04b-TRL4-TVALP-008.002	Characteristics taken from 10m anemometer wind measurements can be used to classify different Bora types.	Average results of 4.15/5 for standard Bora, 3.85/5 for deep Bora and 4.31/5 for gap flow show that validation participants agree that classification algorithm with data from 10m anemometer measurements recognizes Bora types correctly.	OK
		CRT-18-04b-TRL4-TVALP-008.003	Bora classification algorithm correctly recognizes start and end of Bora episodes.	Average results of 3.92/5 for standard Bora and 3.77/5 for gap flow show that validations participants agree that Bora classification algorithm correctly recognizes start and end of Bora episodes.	OK

SESAR Technological Solution Technical Validation Objective ID	SESAR Technological Solution Technical Validation Objective Title	SESAR Technological Solution Success Criterion ID	SESAR Technological Solution Success Criterion	SESAR Technological Solution Validation Results	SESAR Technological Solution Technical Validation Objective Status
				Average result of 3.15/5 for deep Bora was below pre-determined margin, but it was concluded that it is acceptable result from MET perspective because deep Bora is extremely complex wind flow and that even this (first) version of classification algorithm could be of great help for operational forecaster for improving situational awareness.	

Table 11: Technical Validation Results Exercise EXE-18-04b-TRL4-002_CCL

Results on technical feasibility

N/A

Results per KPA

N/A

D.7.2 Analysis of Exercise #04 Results per Technical Validation objective

After Bora measurement campaign, in preparation of the material for the validation exercise, lidar and 10m anemometer data were thoroughly analysed by MET experts and images were prepared for every question in the validation questionnaire, keep in mind the objective of the exercise, to instigate useful discussion among experts.

Validation results are based on operational weather forecasters' and MET experts' judgement, who are the people with vast knowledge and practical experience in analysing the data and deciding on classification algorithm's usefulness in possible future operational use. Validation exercise participants answered set of questions to identify and get answers whether the expected benefits could be achieved. The following methodology was chosen for the evaluation of results:

- Each *Criterion for assessment* could be assessed using values from 1 to 5 by responders (where the full acceptance with the provided statement is represented by the value 5)
- For *Criterion for assessment* to be successfully validated, it was agreed by the experts, that having in mind that it is completely new developed algorithm, the average value had to reach at least 3.3 from responders, which represents 66% of the objective fulfilment.

For each validation objective, the results were transformed into graphs.

In addition to the answers to the questionnaire, number of interesting comments from participants were collected, which provided material for better understanding of participants' answers and presented ground for possible further improvement of Bora wind classification algorithm.

OBJ-18-04b-TRL4-TVALP-008 Results

The aim of validation objective OBJ-18-04b-TRL4-TVALP-008 (Bora wind classification algorithm) is to validate that the Bora wind classification algorithm can be run on measurements derived from the available MET infrastructure and provide correct classification results. The success criteria evaluated in this validation objective has been:

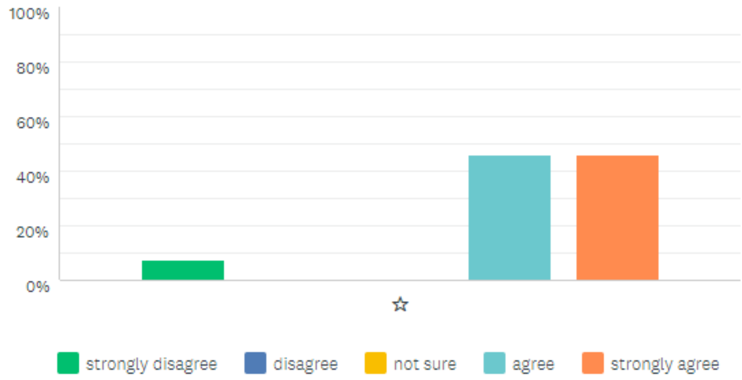
CRT-18-04b-TRL4-TVALP-008.001

For this success criterion, the following hypothesis was postulated: "*Characteristics taken from 10m anemometer wind measurements can be used for Bora wind classification algorithm.*"

This success criterion has been fulfilled in the following way:

Validation exercise participants (operational weather forecasters and MET experts) involved in the validation exercise were shown prepared material and then they were presented with hypothesis and assigned the number from 1 (strongly disagree) to 5 (strongly agree) with optional textual description of answer. Criterion for assessment to be successfully validated, the average value had to reach at least 3.3 from responders, which represents 66% of the objective´s fulfilment.

Question/hypothesis 1: *Does classification algorithm recognize Bora episode?*



	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	7.69% 1	0.00% 0	0.00% 0	46.15% 6	46.15% 6	13	4.23

Figure 26: Question/hypothesis 1 for OBJ-18-04b-TRL4-TVALP-008 evaluation

Average result of 4.23/5 showed that validation participants agree that classification algorithm correctly recognizes Bora episodes. One extreme answer (''1'') was discussed, and it turned out that validator didn't understand completely what was shown on the material and too quickly answered, and that he/she would answer differently, which would in turn raise final average result.

CRT-18-04b-TRL4-TVALP-008.002

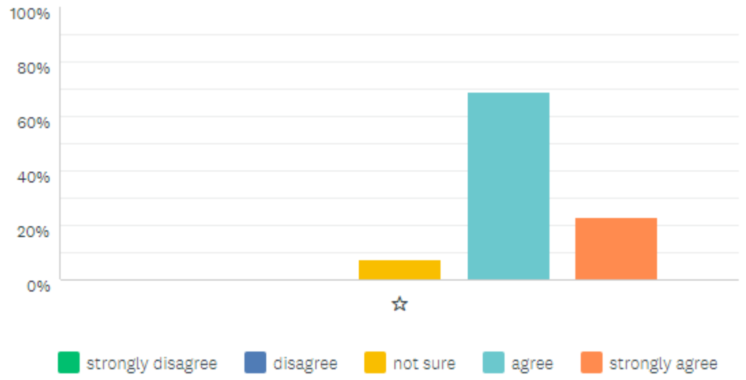
For this success criterion, the following hypothesis was postulated: "*Characteristics taken from 10m anemometer wind measurements can be used to classify different Bora types.*"

This success criterion has been fulfilled in the following way:

As it is extremely important to know behaviour of classification algorithm in different situations, the answer to validation hypothesis/question was tried to be reached by testing algorithm in all 3 types (standard, deep, gap flow).

Validation exercise participants (operational weather forecasters and MET experts) involved in the validation exercise were shown prepared material and then they were presented with hypothesis and assigned the number from 1 (strongly disagree) to 5 (strongly agree) with optional textual description of answer. Criterion for assessment to be successfully validated, the average value had to reach at least 3.3 from responders, which represents 66% of the objective´s fulfilment.

Question/hypothesis 2: *Standard Bora: do you think that the classification algorithm managed to recognize the Bora type correctly?*

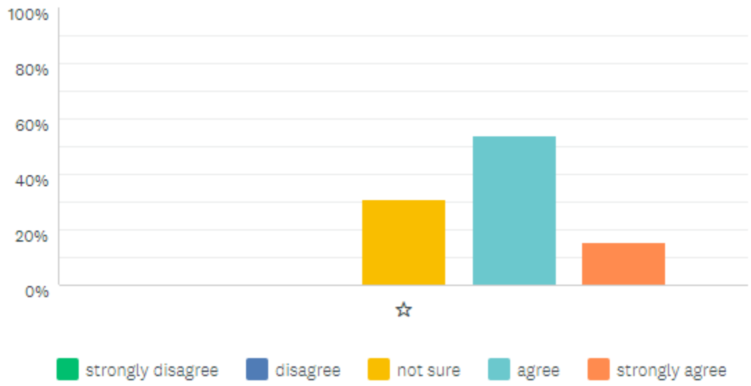


	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	7.69% 1	69.23% 9	23.08% 3	13	4.15

Figure 27: Question/hypothesis 2 for OBJ-18-04b-TRL4-TVALP-008 evaluation

Average result of 4.15/5 showed that validation participants agree that classification algorithm managed to recognize standard Bora correctly. As standard Bora is relatively easy to recognize because of often having wind gusts, this result is expected.

Question/hypothesis 3: *Deep Bora: do you think that the classification algorithm managed to recognize the Bora type correctly?*

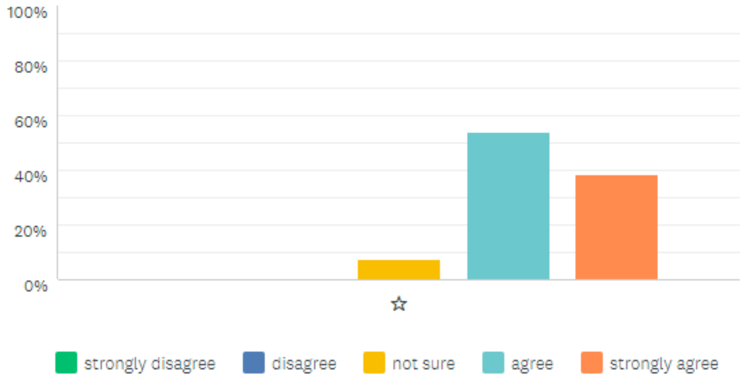


	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	30.77% 4	53.85% 7	15.38% 2	13	3.85

Figure 28: Question/hypothesis 3 for OBJ-18-04b-TRL4-TVALP-008 evaluation

Average result of 3.85/5 for question/hypothesis 3 showed that validation participants agree that classification algorithm managed to recognize deep Bora type correctly. As long episodes of deep Bora were shown, during discussion it was shown that there were few instances in which classification algorithm didn’t recognize Bora type correctly, but it was expected because deep Bora is the most complex type of all the types and algorithm works only on 30min data, which is too long time span for wind flow which can change every few minutes.

Question/hypothesis 4: *Gap flow: do you think that the classification algorithm managed to recognize the Bora type correctly?*



	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	7.69% 1	53.85% 7	38.46% 5	13	4.31

Figure 29: Question/hypothesis 4 for OBJ-18-04b-TRL4-TVALP-008 evaluation

Average result of 4.31/5 showed that validation participants agree that classification algorithm managed to recognize gap flow correctly. Of all the types, it is the most easily recognized type because of its period of occurrence (during night-time) and absence of gusts.

CRT-18-04b-TRL4-TVALP-008.003

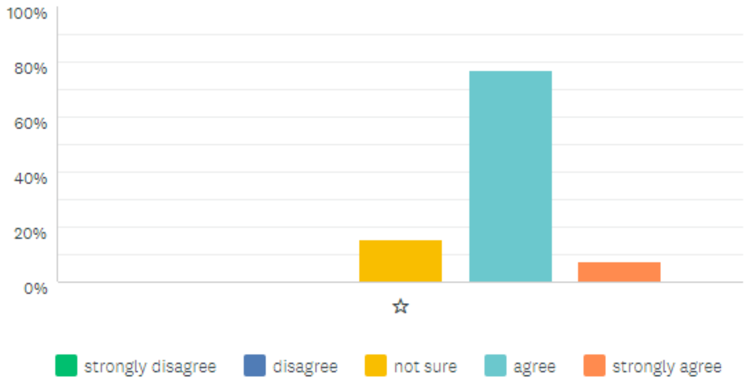
For this success criterion, the following hypothesis was postulated: "*Bora classification algorithm correctly recognizes start and end of Bora episodes.*"

This success criterion has been fulfilled in the following way:

As it is extremely important to know behaviour of classification algorithm in different situations, the answer to validation hypothesis/question was tried to be reached by testing algorithm in all 3 types (standard, deep, gap flow).

Validation exercise participants (operational weather forecasters and MET experts) involved in the validation exercise were shown prepared material and then they were presented with hypothesis and assigned the number from 1 (strongly disagree) to 5 (strongly agree) with optional textual description of answer. Criterion for assessment to be successfully validated, the average value had to reach at least 3.3 from responders, which represents 66% of the objective´s fulfilment.

Question/hypothesis 5: *Standard Bora: do you think that the classification algorithm managed to recognize the beginning and end of the Bora episode correctly?*

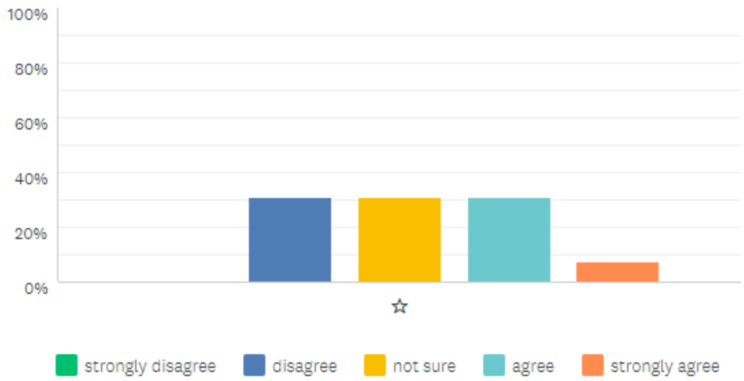


	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	15.38% 2	76.92% 10	7.69% 1	13	3.92

Figure 30: Question/hypothesis 5 for OBJ-18-04b-TRL4-TVALP-008 evaluation

Average result of 3.92/5 showed that validation participants agree that classification algorithm managed to recognize beginning and ending of standard Bora. If we compare this result with result 4.15/5 for recognition of standard Bora, we can see that it is somewhat lower. This is expected, because algorithm can only work with the data that it is fed, and reality is always more complex and hard to wrap than only with data every 30min.

Question/hypothesis 6: *Deep Bora: do you think that the classification algorithm managed to recognize the beginning and end of the Bora episode correctly?*



	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	30.77% 4	30.77% 4	30.77% 4	7.69% 1	13	3.15

Figure 31: Question/hypothesis 6 for OBJ-18-04b-TRL4-TVALP-008 evaluation

This question/hypothesis proved to be the most challenging for classification algorithm, which is evidenced in lowest average result of all the questions in the questionnaire.

Average result of 3.15/5 for question/hypothesis 6 along prepared material show how complex deep Bora wind flow can be. In reality, during long Bora episodes, there could be few Bora types mixed together, so even if 3.15 result is below pre-determined margin for success, it was concluded by experts that the result is acceptable from MET side, especially having in mind that this version of algorithm has taken one 10m anemometer data every 30min into account (from METAR report), which is very big time step for deep Bora, in which wind flow can change every few minutes (**¡Error! No se encuentra el origen de la referencia.**).

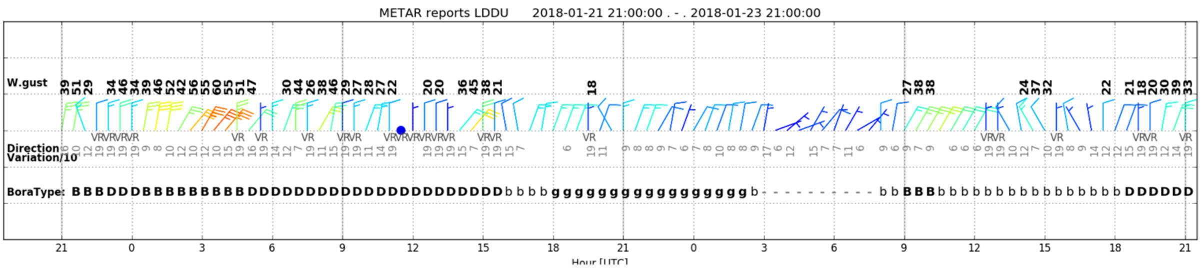
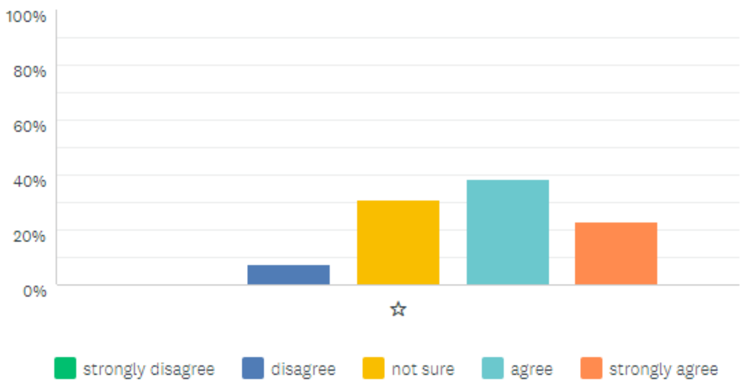


Figure 32: Wind data from METAR reports with classified Bora types (B – standard Bora, D – deep Bora, b - unclassified)

Wind flows at greater heights must also be taken into account, and that's where lidar and wind profiler data could be very useful. If data from the anemometer could be coupled with wind profiles made with wind profiler or lidar, results should be better. Model data are also very useful for being able to determine deep Bora with greater precision. It is ultimately the job of the forecaster to integrate all available data and decide is it deep Bora or any other type of Bora wind.

Question/hypothesis 7: *Gap flow: do you think that the classification algorithm managed to recognize the beginning and end of the Bora episode correctly?*



	STRONGLY DISAGREE	DISAGREE	NOT SURE	AGREE	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	7.69% 1	30.77% 4	38.46% 5	23.08% 3	13	3.77

Figure 33: Question/hypothesis 7 for OBJ-18-04b-TRL4-TVALP-008 evaluation

Average result of 3.77/5 showed that validation participants agree that classification algorithm managed to recognize beginning and ending of gap flow correctly. Result is lower than for recognition of gap flow type (4.31/5), which is somewhat expected because it is more complex to precisely determine beginning and ending than only type. The other reason is more of subjective nature, and that is when there is so easily recognized wind flow like gap flow, forecasters tend to be stricter in their grading than when they are confronted with more complex situation.

During general discussion there were comments about how in some situations classification algorithm is better in determining type, but not beginning and ending, and in other situations vice-versa is true. These characteristics were explained that the algorithm can work only on data that it is fed (in this instance 10m anemometer data every 30min).

In addition to question/hypothesis directly oriented to validation exercise objective, few additional ones were added to the questionnaire with the aim of getting useful operational feedback from operational weather forecasters around topic of possible inclusion of classification algorithm into operational use and possible improvements.

One was *''Do you think it would provide additional benefit to you in situational awareness and improving forecast for LDDU if you would have the Bora classification algorithm operational?''* which received average result of 4.08/5 and another was *''Would you find useful to have parallel view of ALADIN vertical wind profile and classification from model and METAR reports in operational use?''* received average result of 4.62/5. Both results are strongly in favour of including Bora classification algorithm in future use, with additional improvements like adding wind profile data from model to classification results, which could greatly improve forecaster's situational awareness.

Forecaster's duty is to look at every possible available data so it was concluded that classification algorithm, in addition with wind profiler and model wind data, could be very valuable tool in the future that could help mostly forecasters and then also other future users in raising their situational awareness to determine in which Bora situation are they in the moment and what they could expect of it.

D.7.3 Unexpected Behaviours/Results

There was no unexpected behaviours/results in this validation exercise.

D.7.4 Confidence in Results of Validation Exercise #04

Level of significance/limitations of Technical Validation Exercise Results

Results obtained in technical validation exercise EXE-18-04b-TRL4-002_CCL are representative because validation participants were operational forecasters and MET experts from CCL/COOPANS which have vast theoretical and practical operational knowledge about Bora wind problematics. In addition, Bora episodes that were taken for the questionnaire were selected with great care and having in mind their overall significance and representativeness.

High average results obtained in the questionnaire show that validation participants are confident about results obtained from Bora classification algorithm and its usefulness in their operational work.

Quality of Technical Validation Exercises Results

During the technical validation exercise all operational forecasters and MET experts from CCL/COOPANS, with vast theoretical and practical knowledge of Bora wind problematics, were present and were active during questionnaire and following discussion. Bora episodes taken for the questionnaire were selected with great care, and having in mind their overall significance and representativeness, quality of results are considered to be very high.

Significance of Technical Validation Exercises Results

Having in mind number of validation participants and their knowledge and number and overall representativeness of chosen Bora episodes (all Bora types were taken into account and as historical cases were taken, environment is the same as in reality), results obtained have both statistical and operational significance.

D.7.5 Conclusions

The aim of the technical validation exercise was to validate that Bora classification algorithm can be run on measurements derived from the available MET infrastructure and provide correct classification results. To achieve this goal, three success criteria were defined.

First, "*Characteristics taken from 10m anemometer wind measurements can be used for Bora wind classification algorithm.*", has been fulfilled because average result of 4.23/5 shows that validation participants agree that classification algorithm, which used 10m anemometer data, correctly recognizes Bora episodes.

Second success criterion, "*Characteristics taken from 10m anemometer wind measurements can be used to classify different Bora types.*", has been approached by dividing it into three situations, one for every Bora type (standard Bora, deep Bora, gap flow), which raises its statistical and operational significance. Average results, 4.15/5 (standard Bora), 3.85/5 (deep Bora) and 4.31/5 (gap flow), show that validation participants agree that classification algorithm correctly recognizes Bora types in different situations.

Third success criterion, "*Bora classification algorithm correctly recognizes start and end of Bora episodes.*", has also been approached by dividing it into three situations, one for every Bora type, which raises its statistical and operational significance. Average results, 3.92/5 (standard Bora) and 3.77/5 (gap flow), show that validation participants agree that classification algorithm correctly recognizes start and end of Bora episodes in different situations. Average result for deep Bora, 3.15/5, was additionally analysed and discussed and it was concluded that, when overall complexity of deep Bora wind flow is taken into account, the result is acceptable from MET side. Recommendations were derived and mentioned in the next chapter.

During general discussion there were comments about how in some situations classification algorithm is better in determining type, but not beginning and ending, and in other situations vice-versa is true. These characteristics were explained that the algorithm can work only on data that it is fed (in this instance 10m anemometer data every 30min).

Following positive answer to additional question, *''Do you think it would provide additional benefit to you in situational awareness and improving forecast for LDDU if you would have the Bora classification* *algorithm operational?*'', which received result 4.08/5, it was concluded that Bora classification algorithm would provide great help to operational forecaster, especially in improving forecaster's situational awareness.

Conclusions on technical feasibility

N/A

Conclusions on performance assessments

N/A

D.7.6 Recommendations

1) Higher time resolution of measured data:

During general discussion there were comments about how in some situations classification algorithm is better in determining type, but not beginning and ending, and in other situations vice-versa is true. These characteristics were explained that the algorithm can work only on data that it is fed (in this instance 10m anemometer data every 30min).

On these comments continues the discussion regarding deep Bora and its complexity. As already mentioned, this version of algorithm has taken only 30min 10m anemometer data into account, which is very big time step for deep Bora, in which wind flow can change every few minutes. Future work should strive to include as high resolution data as possible (minute or even second resolution).

2) Inclusion of wind profiler, lidar and model data:

Another problem with deep Bora is that wind flows at greater heights must also be taken into account, and that's where lidar and wind profiler data could be very useful. If data from the anemometer could be coupled with wind profiles made with wind profiler or lidar, results should be better. Model data are also very useful for being able to determine deep Bora with greater precision. This reasoning was supported when question *''Would you find useful to have parallel view of ALADIN vertical wind profile and classification from model and METAR reports in operational use?''* received average result of 4.62/5, and therefore strong support from operational forecasters.

Forecaster's duty is to look at every possible available data so it was concluded that classification algorithm, in addition with wind profiler and model wind data, could be very valuable tool in the future that could help mostly forecasters and then also other future users in raising their situational awareness to determine in which Bora situation are they in the moment and what they could expect of it.

Appendix E Technical Validation Exercise #05 Report (EXE-18-04b-TRL6-004_LDO "GWMS SWIM Enhancement")

E.1 Summary of the Technical Validation Exercise #05 Plan

As in the TVALP of PJ.18-04b.

E.2 Technical Validation Exercise #05 description and scope

The EXE-18-04b-TRL6-004_LDO reports on the validation of the technical SWIM compatibility of the local 4DWxCube technical system, instantiated by the GWMS prototype the core and concept of which has been developed in SESAR1, although without the capability to provide its output as standard and specialized SWIM services. To this end, non-standard MET SWIM services such as METForTAM [39] have been developed and validated elsewhere [46]. Standard MET services (METAR) have been advanced with SWIM Purple Profile binding and subscription of aircraft based MET measurements via Purple Profile has been developed as it has been used to validate SWIM Purple Profile technical infrastructure (TI). The latter two are subject to this report which focuses on the provider/consumer side not considered in the PJ17-01 EXE1 report **¡Error! No se encuentra el origen de la referencia.** which deals with the validation of the TI. Service provision and consumption of GWMS have been enabled by the PJ17-01 EXE-1 SWIM Purple Profile technical infrastructure platform of LDO, to the validation of which it also contributed.

In the exercise EXE-17.01-TRL6-TVALP-EXE1.0001 of PJ17-01, the GWMS prototype was used with an extension able to negotiate publication and subscription with a Purple Profile ground node. It was set to provide the METAR service, so far defined for SWIM Yellow Profile, on Purple Profile employing request/reply and publish/subscribe message exchange patterns. The airborne consumer as well as the provider of A/C MET data was the LDO A/C-simulator in Turin, alongside several other ground based consumers. GWMS fetched A/C based MET observations from the A/C simulator as the METEOPROBE service (LEONARDO Italy proprietary service, no official SWIM Service nor modelled in MEGA or part of EATMA yet), again both on request and on subscription using the ground node situated in Rome.

E.3 Summary of Exercise #05 Technical Validation Objectives and success criteria

Below are the details about Validation objectives, related requirements and the success criteria applicable to the objective listed.

[OBJ]

Identifier	OBJ-18-04b-TRL6-TVALP-001
Objective	To validate that the GWMS as local 4DWxCube fulfils general SWIM functionalities and settings required to provide and receive SWIM services.
Title	4DWxCube general SWIM functionalities

Category	<technical feasibility>
Key environment conditions	Nominal and adverse weather conditions
TRL Phase	TRL6

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC22.0010
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC22.0060
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[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL6-TVALP-001.001	It is possible to provide MET Information as SWIM services to stakeholders.
CRT-18-04b-TRL6-TVALP-001.002	It is possible to accommodate new SWIM services without major redesign of the GWMS.
CRT-18-04b-TRL6-TVALP-001.003	The GWMS is able to support 10000 subscriptions simultaneously.

CRT-18-04b-TRL6-TVALP-001.004	The GWMS authentication by users is done between SWIM nodes.
CRT-18-04b-TRL6-TVALP-001.005	The GWMS does allow the configuration of SSL-based transport protocol (AMQPS) for metadata and data transfer to maintain data security.
CRT-18-04b-TRL6-TVALP-001.006	The GWMS is designed according to Service-oriented architecture (SOA) principles.
CRT-18-04b-TRL6-TVALP-001.007	The GWMS allows issuing alerts to indicate that parts or all of the MET Information of a service is not available, out of date or cannot be generated.
CRT-18-04b-TRL6-TVALP-001.008	The GWMS delivers MET Services to local ATM consumers within a maximum delivery time depending on the MET product.
CRT-18-04b-TRL6-TVALP-001.009	The GWMS delivers MET Services to local ATM consumers using either SWIM Yellow or Purple Profile.
CRT-18-04b-TRL6-TVALP-001.010	The GWMS provides services compliant with the latest releases of SESAR AIRM and ISRM except when duly justified.

[OBJ]

Identifier	OBJ-18-04b-TRL6-TVALP-002
Objective	To validate that the GWMS provides reliable subscription management functionalities.
Title	MET SWIM service subscription management
Category	technical feasibility
Key environment conditions	Nominal weather conditions
TRL Phase	TRL6

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	18-04b
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<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC22.0030
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<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC22.0390
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[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL6-TVALP-002.001	The GWMS notifies users if a MET product within a service is not available.
CRT-18-04b-TRL6-TVALP-002.002	The GWMS always includes the latest available product.
CRT-18-04b-TRL6-TVALP-002.003	The GWMS provides an API to allow users to specify their requests.
CRT-18-04b-TRL6-TVALP-002.004	The GWMS provides an API to allow users to specify their subscription profiles.
CRT-18-04b-TRL6-TVALP-002.005	The GWMS provides a message if a subscription is valid or not.
CRT-18-04b-TRL6-TVALP-002.006	The GWMS negotiates communication with the SWIM infrastructure (node) only using a certificate.

[OBJ]

Identifier	OBJ-18-04b-TRL6-TVALP-003
Objective	To validate that the GWMS provides different service payloads.
Title	MET SWIM service payload management
Category	technical feasibility
Key environment conditions	Nominal and adverse weather conditions
TRL Phase	TRL6

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC22.0250

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL6-TVALP-003.001	The GWMS provides complex services in addition to standard services.

[OBJ]

Identifier	OBJ-18-04b-TRL6-TVALP-004
Objective	To validate that the GWMS is able to provide a PP SWIM service correctly.
Title	MET PP SWIM service design
Category	technical feasibility
Key environment conditions	Nominal weather conditions
TRL Phase	TRL6

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	18-04c
<COVERS>	<ATMS Requirement>	TBD from 18-04c TS

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL6-TVALP-004.001	GWMS (specific instance at an airport) receives request for METAR service (adapted to AMQPS 1.0) by an A/C application using routing of the request based on ICAO code of the airport. GWMS replies message with meta data in such a way that it is routed to the right requestor.
CRT-18-04b-TRL6-TVALP-004.002	GWMS (specific instance at an airport) receives subscription for METAR service (adapted to AMQPS 1.0) by an A/C application using routing of the subscription request based on ICAO code of the airport. GWMS publishes the payload with meta data in such a way that it is routed to the right subscriber.

[OBJ]

Identifier	OBJ-18-04b-TRL6-TVALP-005
Objective	To validate that the GWMS is able to receive A/C MET observations as PP SWIM service downlink correctly and use them for winds aloft products.

Title	MET PP SWIM service design
Category	technical feasibility
Key environment conditions	Nominal weather conditions
TRL Phase	TRL6

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC31.0060

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL6-TVALP-005.001	GWMS is sending correct subscription messages that are accepted by the SWIM PP ground node.
CRT-18-04b-TRL6-TVALP-005.002	A/C MET observations subscribed and filtered using the right filter criteria are received correctly by GWMS.
CRT-18-04b-TRL6-TVALP-005.003	GWMS is sending correct unsubscribe messages that are accepted by the SWIM PP ground node and lead to unsubscribe of previously subscribed messages.

E.4 Summary of Technical Validation Exercise #05 Validation scenarios

The reference scenario is the GWMS platform and the functionalities as developed and described in SESAR 1 [47].

Solution scenario: The GWMS platform has been extended to cover new FB MET-FATE and new functionalities with respect to the provision of MET SWIM services according to yellow and purple profile. Here, this capability of providing SWIM services has been tested using the SWIM TI platform for purple profile of EXE-17.01-TRL6-TVALP-EXE1.0001 in PJ17-01. Both provision and consumption have been tested. For the latter, A/C is used as a sensor and from the data wind in the vicinity of the airport is being processed and displayed in order to show that the data are usable to generate glide path wind profiles needed in METForWTS (Appendix B).

E.5 Summary Technical Validation Exercise #05 Assumptions

It is assumed that technical compliance of the local 4DWxCube with yellow profile is established by participation in VAL EXE PJ.04.02-V2.04 in PJ04-02 where the METForTAM service has been implemented and provided via AMQP 1.0, albeit using a standard qpid broker and not a fully YP compliant SWIM node. This was not required by the EXE and does not present a problem since YP communication of local MET services has been already validated in SESAR1 and proper subscription at a SWIM node could be easily provided according to the METForTAM SDD.

E.6 Deviation from the planned activities

N/A

E.7 Technical Validation Exercise #05 Validation Results

E.7.1 Summary of Technical Validation Exercise #05 Results

Technical Validation Exercise #05 Validation Objective ID	Technical Validation Exercise #05 Validation Objective Title	Technical Validation Exercise #05 Success Criterion ID	Technical Validation Exercise #05 Success Criterion	Technical Validation Exercise #05 Results	Technical Validation Exercise #05 Validation Objective Status
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.001	It is possible to provide MET Information as SWIM services to stakeholders	services provided to ground based and airborne users	OK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.002	It is possible to accommodate new SWIM services without major redesign of the GWMS.	New services have been implemented without changing GWMS core	OK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.003	The GWMS is able to support 10000 subscriptions simultaneously.	Not tested	NOK

Technical Validation Exercise #05 Validation Objective ID	Technical Validation Exercise #05 Validation Objective Title	Technical Validation Exercise #05 Success Criterion ID	Technical Validation Exercise #05 Success Criterion	Technical Validation Exercise #05 Results	Technical Validation Exercise #05 Validation Objective Status
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.004	The GWMS authentication by users is done between SWIM nodes.	Authentication tested between client and SWIM Node. Authentication between SWIM nodes does not concern providers and consumers.	OK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.005	The GWMS does allow the configuration of SSL-based transport protocol (AMQPS) for metadata and data transfer to maintain data security.	Successfully used in exercise	OK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.006	The GWMS is designed according to Service-oriented architecture (SOA) principles.	SOA design is the GWMS core principle	OK

Technical Validation Exercise #05 Validation Objective ID	Technical Validation Exercise #05 Validation Objective Title	Technical Validation Exercise #05 Success Criterion ID	Technical Validation Exercise #05 Success Criterion	Technical Validation Exercise #05 Results	Technical Validation Exercise #05 Validation Objective Status
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.007	The GWMS allows issuing alerts to indicate that parts or all of the MET Information of a service is not available, out of date or cannot be generated.	Services used are not designed to provide alerts, but it is no principle problem to implements such services from a design point of view. Information about missing information is included.	NOK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.008	The GWMS delivers MET Services to local ATM consumers within a maximum delivery time depending on the MET product.	Not included and tested in any exercise	NOK
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.009	The GWMS delivers MET Services to local ATM consumers using either SWIM Yellow or Purple Profile.	Demonstrated in exercise	OK

Technical Validation Exercise #05 Validation Objective ID	Technical Validation Exercise #05 Validation Objective Title	Technical Validation Exercise #05 Success Criterion ID	Technical Validation Exercise #05 Success Criterion	Technical Validation Exercise #05 Results	Technical Validation Exercise #05 Validation Objective Status
OBJ-18-04b-TRL6-TVALP-001	4DWxCube general SWIM functionalities	CRT-18-04b-TRL6-TVALP-001.010	The GWMS provides services compliant with the latest releases of SESAR AIRM and ISRM except when duly justified.	METAR service compliant to AIRM and ISRM. METEOPROBE is not yet mapped to AIRM.	OK
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.001	The GWMS notifies users if a MET product within a service is not available.	Currently not implemented	NOK
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.002	The GWMS always includes the latest available product.	Correctly done during exercise	OK
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.003	The GWMS provides an API to allow users to specify their requests.	This is automatically fulfilled by adhering to service interfaces	OK
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription management	CRT-18-04b-TRL6-TVALP-002.004	The GWMS provides an API to allow users to specify their	Not clear what a subscription profile should be as the	N/A

Technical Validation Exercise #05 Validation Objective ID	Technical Validation Exercise #05 Validation Objective Title	Technical Validation Exercise #05 Success Criterion ID	Technical Validation Exercise #05 Success Criterion	Technical Validation Exercise #05 Results	Technical Validation Exercise #05 Validation Objective Status
			subscription profiles.	whole point of the SWIM TI is to decouple provider and consumer in space and time. Requirement should be deleted.	
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription managemen t	CRT-18-04b-TRL6-TVALP-002.005	The GWMS provides a message if a subscription is valid or not.	Part of subscription management done by the SWIM node. Out of scope.	N/A
OBJ-18-04b-TRL6-TVALP-002	MET SWIM service subscription managemen t	CRT-18-04b-TRL6-TVALP-002.006	The GWMS negotiates communicati on with the SWIM infrastructur e (node) only using a certificate.		
OBJ-18-04b-TRL6-TVALP-003	MET SWIM service payload managemen t	CRT-18-04b-TRL6-TVALP-003.001	The GWMS provides complex services in addition to standard services.	Realised during exercise	OK
OBJ-18-04b-TRL6-TVALP-004	MET PP SWIM	CRT-18-04b-TRL6-TVALP-004.001	GWMS (specific instance at	Done as described	OK

Technical Validation Exercise #05 Validation Objective ID	Technical Validation Exercise #05 Validation Objective Title	Technical Validation Exercise #05 Success Criterion ID	Technical Validation Exercise #05 Success Criterion	Technical Validation Exercise #05 Results	Technical Validation Exercise #05 Validation Objective Status
	service design		an airport) receives request for METAR service (adapted to AMQPS 1.0) by an A/C application using routing of the request based on ICAO code of the airport. GWMS replies message with meta data in such a way that it is routed to the right requestor.	during exercise	
OBJ-18-04b-TRL6-TVALP-004	MET PP SWIM service design	CRT-18-04b-TRL6-TVALP-004.002	GWMS (specific instance at an airport) receives subscription for METAR service (adapted to AMQPS 1.0) by an A/C application using routing of the subscription	Done as described during exercise	OK

Technical Validation Exercise #05 Validation Objective ID	Technical Validation Exercise #05 Validation Objective Title	Technical Validation Exercise #05 Success Criterion ID	Technical Validation Exercise #05 Success Criterion	Technical Validation Exercise #05 Results	Technical Validation Exercise #05 Validation Objective Status
			request based on ICAO code of the airport. GWMS publishes the payload with meta data in such a way that it is routed to the right subscriber.		
OBJ-18-04b-TRL6-TVALP-005	MET PP SWIM service design	CRT-18-04b-TRL6-TVALP-005.001	GWMS is sending correct subscription messages that are accepted by the SWIM PP ground node.	Done as described during exercise	OK
OBJ-18-04b-TRL6-TVALP-005	MET PP SWIM service design	CRT-18-04b-TRL6-TVALP-005.002	A/C MET observations subscribed and filtered using the right filter criteria are received correctly by GWMS.	Done as described during exercise for “Flight Phase” attribute	OK
OBJ-18-04b-TRL6-TVALP-005	MET PP SWIM	CRT-18-04b-TRL6-TVALP-005.003	GWMS is sending correct unsubscripti	Done as described	OK

Technical Validation Exercise #05 Validation Objective ID	Technical Validation Exercise #05 Validation Objective Title	Technical Validation Exercise #05 Success Criterion ID	Technical Validation Exercise #05 Success Criterion	Technical Validation Exercise #05 Results	Technical Validation Exercise #05 Validation Objective Status
	service design		on messages that are accepted by the SWIM PP ground node and lead to unsubscription of previously subscribed messages.	during exercise	

Table 12: Technical Validation Results Exercise #05

Results on technical feasibility

Technical feasibility of providing GWMS output and receiving input as SWIM services has been shown for the purple profile. Combined with the result of VAL EXE PJ.04.02-V2.04 in PJ04-02 the same can be inferred for the yellow profile for which no separate test using a real SWIM node has been performed. Additionally, this has been already demonstrated in general in EXE-669 of OFA05.01.01 in SESAR1.

Results per KPA

N/A

E.7.2 Analysis of Exercise #05 Results per Technical Validation objective

OBJ-18-04b-TRL6-TVALP-001 Results

This objective had the aim “to validate that the GWMS as local 4DWxCube fulfils general SWIM functionalities and settings required to provide and receive SWIM services”.

As a first success criterion, CRT-18-04b-TRL6-TVALP-001.001, it is listed that it is to be “possible to provide MET Information as SWIM services to stakeholders”. This has been shown by the fact that the METAR service has been provided on request-reply and a publish-subscribe basis over a purple profile compliant SWIM node in EXE-17.01-TRL6-TVALP-EXE1.0001. Therefore, given the assumptions stated above, application of both profiles so far relevant for MET services, i.e. YP and PP, is feasible. The fact that in VAL EXE PJ.04.02-V2.04 in PJ04-02 there was no SWIM node over which the METForTAM service has been provided, but a broker simply following the AMQP 1.0 standard is deemed no issue, because subscription handling including authentication, encryption etc. has been shown in the EXE-17.01-TRL6-TVALP-EXE1.0001 for PP which is not a fundamentally different process than in YP.

The second success criterion, CRT-18-04b-TRL6-TVALP-001.002, demands that it be possible to accommodate new SWIM services without major redesign of the GWMS. This has been shown by the seamless integration of the METForTAM service in VAL EXE PJ.04.02-V2.04 in PJ04-02.

CRT-18-04b-TRL6-TVALP-001.003 asked that the GWMS be able to support 10000 subscriptions simultaneously. As this was not party of either exercise, this could not be tested. However, since the GWMS takes only the role of a service provider and the decoupling of provider and consumer is the job of the SWIM TI, it is proposed that this SC be not applicable.

CRT-18-04b-TRL6-TVALP-001.004 says that “the GWMS authentication by users is done between SWIM nodes”. This criterion is misleading since the authentication of a service provider and/or consumer is done between the client and the SWIM Node. This, however, has been demonstrated in EXE-17.01-TRL6-TVALP-EXE1.0001.

CRT-18-04b-TRL6-TVALP-001.005 requires the GWMS to allow the configuration of SSL-based transport protocol (AMQPS) for metadata and data transfer to maintain data security. Since AMQPS has been successfully used in VAL EXE PJ.04.02-V2.04 in PJ04-02, this one was successful.

CRT-18-04b-TRL6-TVALP-001.006, is not testable, but only to be validated by review of design: “The GWMS is designed according to Service-oriented architecture (SOA) principles.” However, since the SOA principle is at the core of the GWMS prototype, this one is fulfilled.

CRT-18-04b-TRL6-TVALP-001.007, “The GWMS allows issuing alerts to indicate that parts or all of the MET Information of a service is not available, out of date or cannot be generated.” Could not be shown, because this is currently not foreseen in the design of any of the MET services. To some extent, this is implicitly provided by the METForTAM payload, because its design also shows empty tags for the products not provided. However, in case such alerting is explicitly required by a service, the design of the GWMS is fit for purpose. Internally it already uses such a scheme.

CRT-18-04b-TRL6-TVALP-008, “The GWMS delivers MET Services to local ATM consumers within a maximum delivery time depending on the MET product.” Contains a non-functional requirement too unspecific to be validated.

CRT-18-04b-TRL6-TVALP-009 ,“The GWMS delivers MET Services to local ATM consumers using either SWIM Yellow or Purple Profile.”, was implicit in both EXEs.

CRT-18-04b-TRL6-TVALP-010, “The GWMS provides services compliant with the latest releases of SESAR AIRM and ISRM except when duly justified.” is a service requirement that is however fulfilled by METForTAM.

OBJ-18-04b-TRL6-TVALP-002 Results

This is an essential requirement for any publish/subscribe service. For the time being and the use of prototypes in validation exercises the objective was fulfilled by subscribing/unsubscribing actions to a service. A dedicated API of GWMS is not in line with the SOA principle as it is the Services Interfaces through which communication with consumers is facilitated. YP and PP services are fully supported and can be subscribed to or delivered to consumers. Change or deletion of the respective requirement is proposed.

OBJ-18-04b-TRL6-TVALP-003 Results

This objective is fully covered by providing METAR as standard message but newly as PP service (so far only as YP service available). According to the assumptions, it is to be noted that the METForTAM service is a very complex service specifically developed for TAM concept.

OBJ-18-04b-TRL6-TVALP-004 Results

During EXE-17.01-TRL6-TVALP-EXE1.0001 using the technical infrastructure platform for PP, the provision of PP service by GWMS has been demonstrated using Request/Reply and Publish/Subscribe message exchange patterns.

OBJ-18-04b-TRL6-TVALP-005 Results

In line with the objective OBJ-18-04b-TRL6-TVALP-004, GWMS demonstrated not only the provision of PP services but also the ability to subscribe, receive and unsubscribe to a PP service. The objective has been fully validated by receiving a PP service from an A/C.

E.7.3 Unexpected Behaviours/Results

N/A

E.7.4 Confidence in Results of Validation Exercise #05

Level of significance/limitations of Technical Validation Exercise Results

The results of this exercise can be considered as highly significant, since the platform employed in EXE-17.01-TRL6-TVALP-EXE1.0001 had been set up to validate the technical specification of the purple profile and featured ground as well as airborne SWIM TI as well as multiple providers and consumers, e.g. for digital NOTAM, ground MET and A/C measured MET. Limitations are presented by the requirements not covered by the EXE as far as they concern the communication of the client with the SWIM node. This pertains to administration of certificates which were just assumed to be valid and message level security which was not required by any of the applications involved. As explained above, it is not considered a limitation that only the PP has been tested in this exercise, since the fact that local MET services over YP have been tested in EXE 669 in SESAR1 and the YP METForTAM service has been provided successfully in VAL EXE PJ.04.02-V2.04 in PJ04-02, albeit without a SWIM node.

Quality of Technical Validation Exercises Results

The results were as planned. The METAR service was correctly forwarded to the subscribing or requesting consumers and the A/C MET data (METEOPROBE service, no official SWIM service) has been received as subscribed and filtered according to flight phase in order to receive only measurements near the aerodrome.

Significance of Technical Validation Exercises Results

Since EXE-17.01-TRL6-TVALP-EXE1.0001 had been set up in a realistic manner with a flight simulator and ground and airborne SWIM nodes as well as several ground and airborne providers and consumers and featured a storyboard constructed around a simulated flight from Vienna to Milan.

Although not part of the actual validation exercise, Figure 34 shows a subsequent test integration of the A/C measured MET data received via purple profile into the WISADS (SmartWx) platform developed as a MET Alerting tool for APOC in SESAR1. It is to be used in Total Airport Management as an implementation of part of the functional block “Meteorological Operational Translation” (ENs Airport-10 and Airport-11), the main consumer of the METForTAM service. How exactly A/C derived MET data are to be used in the APOC context is a topic for future versions of the METForTAM service (single A/C values or compiled profiles). Here it shall only serve to underline the significance of the results of the validation exercise.

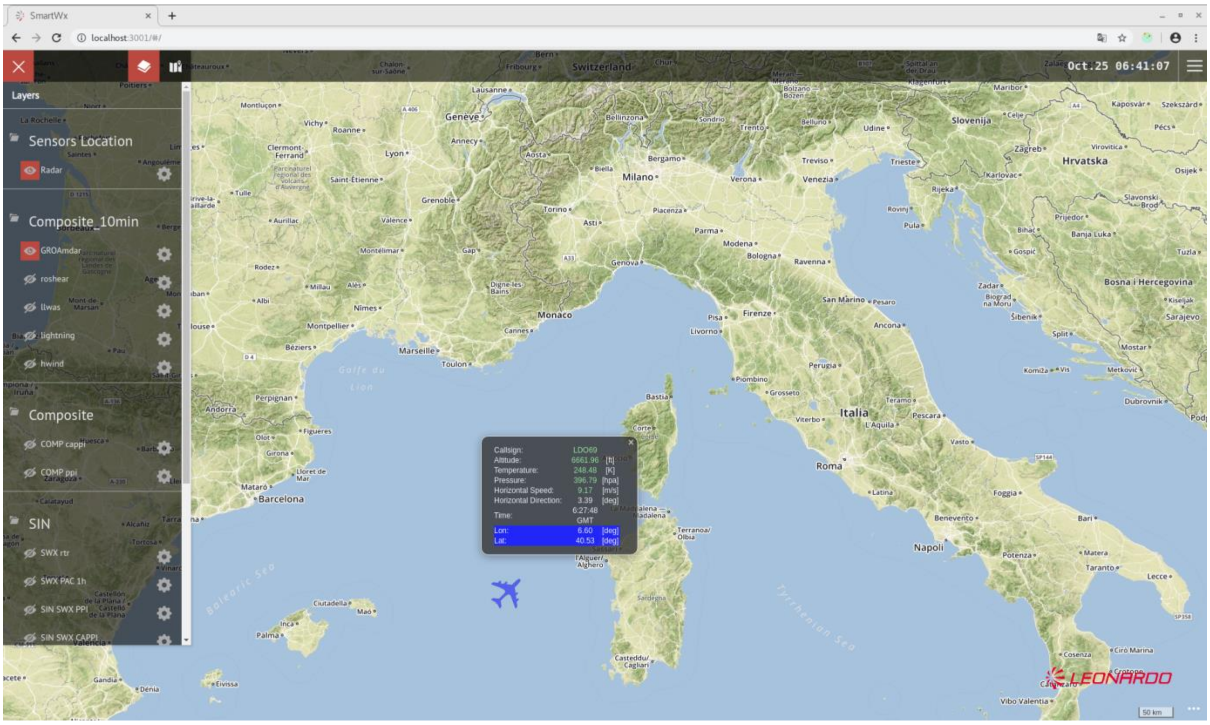

Figure 34: Integration of METEOPROBE data into the SmartWx/WISADS platform demonstrating the usability for translation of local MET, in this case for the Airport Operations Centre

E.7.5 Conclusions

Conclusions to be drawn from this validation exercise are on technical feasibility of the local 4DWxCube as the platform providing all local MET as SWIM services, especially for the newly developed purple profile for air-ground communication.

Conclusions on technical feasibility

As the main result of this exercise it can be concluded that the concept of the local 4DWxCube as the platform for the provision of local MET, i.e. MET information for local operations as well as MET information generated locally which is not the same in general, as SWIM services is technically feasible.

Conclusions on performance assessments

N/A

E.7.6 Recommendations

It is recommended to strive for concrete deployment of instances of local 4DWxCubes as single platforms to provide local MET as SWIM services, since all elements are now present. Furthermore, it is recommended to further provision of aircraft derived MET data as a PP SWIM service since receiving the data in real time and not in packages as currently provided for assimilation in numerical weather prediction models can be very valuable for advanced applications and services for local MET (of course not for local MET only) such as METForWTS (supporting the quality of glidepath wind). Another recommendation concerns the provision of local MET or MET in general as purple profile services for onboard applications. During the course of project 18-04b it has become apparent that it is a major concern of airspace users to not relay sensitive data about aircraft needed to tailor and filter MET information (e.g. with respect to location) to MET authorities. With regard to this, it had been discussed to provide MET only over YP and do the tailoring in airspace user centres subsequently providing the tailored service as PP. This is slightly in conflict with the architectural requirement of the weather cubes (local or regional) as operated by ATM MET being the sole source of tailored MET and complicates the architecture. Therefore, it is recommended to consider deployment scenarios making use of the intrinsic capabilities of the PP as demonstrated by the set-up employed in EXE-17.01-TRL6-TVALP-EXE1.0001 and the technical specification of SWIM PP in general in order to meet this privacy requirement. It emerged that the design of purple profile SWIM nodes building on the AMQP 1.0 standard allow for providing these filter capabilities by default. This means that it is not a matter of the physical location of the service provider but only of the operator of the SWIM ground node the A/C connects to that grants control over all information needed to configure the actual information being relayed to a subscriber.

Appendix F Technical Validation Exercise #06 Report (EXE-18-04b-TRL6-005_LDO "GWMS: Swapping MET providers")

F.1 Summary of the Technical Validation Exercise #06 Plan

As in the TVALP of 18-04b.

F.2 Technical Validation Exercise #06 description and scope

This exercise is another rather internal exercise where the provider of a MET product changes. Therefore, actors are only two MET providers who both deliver information about convective cells based on Weather Radar data. This information is used to fill the Convection data element of the METForTAM service.

The GWMS as local 4DWxCube prototype demonstrates therefore that different sources can be used for providing MET SWIM services or fill different data elements of a service. This is important for operational consumers who might prefer a specific source due to manifold reasons (e.g. policy, quality of data, temporal or spatial resolution, etc.).

There is only one validation scenario executed by running default input, and then switching to the other input and the output of both runs are logged. Later the results will be compared and gaps or other differences will be explained.

F.3 Summary of Exercise #06 Technical Validation Objectives and success criteria

Below the details are listed about Validation objectives, related requirements and the success criteria applicable to the objective.

[OBJ]

Identifier	OBJ-18-04b-TRL6-TVALP-011
Objective	To validate that the local 4DWxCube is able to switch MET product providers.
Title	Switch of MET product provider
Category	<technical feasibility>
Key environment conditions	Nominal and adverse weather conditions
TRL Phase	TRL6

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b

<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC31.0070

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL6-TVALP-011.001	Connection to second provider is successfully established.
CRT-18-04b-TRL6-TVALP-011.002	METForTAM service is correctly provided with GWMS proprietary convection algorithm.
CRT-18-04b-TRL6-TVALP-011.003	METForTAM service is successfully swapped to new input using RadTRAM convection algorithm.
CRT-18-04b-TRL6-TVALP-011.004	Gaps in convection product data elements within METForTAM service are documented.

F.4 Summary of Technical Validation Exercise #06 Validation scenarios

The reference scenario is the GWMS platform and the functionalities as developed and described in SESAR 1 [47].

Solution Scenario: The GWMS platform has been extended to cover new functionalities with respect to the provision of MET SWIM services according to yellow and purple profile and to incorporate new capabilities developed in SESAR2020 (e.g. glide path wind). Here, the capability of the GWMS prototype to be supplied with products of different providers will be tested. To this end, two different prototypes for the provision of convection cells will be used as input to fill the Convection data element in the METForTAM service.

One of these prototypes will be the RadTRAM system developed by DLR [55][57], and the other is the Thunderstorm product (observation and forecast) developed for GWMS on the basis of requirements from OFA05.01.01 [55].

F.5 Summary Technical Validation Exercise #06 Assumptions

N/A

F.6 Deviation from the planned activities

No deviations occurred.

F.7 Technical Validation Exercise #06 Validation Results

F.7.1 Summary of Technical Validation Exercise #06 Results

Technical Validation Exercise #06 Validation Objective ID	Technical Validation Exercise #06 Validation Objective Title	Technical Validation Exercise #06 Success Criterion ID	Technical Validation Exercise #06 Success Criterion	Technical Validation Exercise #06 Results	Technical Validation Exercise #06 Validation Objective Status
OBJ-18-04b-TRL6-TVALP-011	Switch of MET product provider	CRT-18-04b-TRL6-TVALP-011.001	Connection to second provider is successfully established.	Connection to URL from DLR established and product files are retrieved.	OK
OBJ-18-04b-TRL6-TVALP-011	Switch of MET product provider	CRT-18-04b-TRL6-TVALP-011.002	METForTAM service is correctly provided with GWMS proprietary convection algorithm.	METForTAM has run with default input source.	OK
OBJ-18-04b-TRL6-TVALP-011	Switch of MET product provider	CRT-18-04b-TRL6-TVALP-011.003	METForTAM service is successfully swapped to new input using RadTRAM convection algorithm.	METForTAM was still provided but RadTRAM input source was used.	OK
OBJ-18-04b-TRL6-TVALP-011	Switch of MET product provider	CRT-18-04b-TRL6-TVALP-011.004	Gaps in convection product data elements within METForTAM service are documented .	Log files were generated and stored during complete exercise. Content is compared between output files for the two different	OK

				input sources.	

Table 13: Technical Validation Results Exercise #06

Results on technical feasibility

The change of an input source is an important capability for prototypes like the GWMS which is acting as a local 4DWxCube installed at an airport. The MET SWIM services are the information needed for an operational concept but the input can be filled by different MET providers.

Precondition is the mapping of all data elements so that the service messages can be filled or not and an appropriate converter must be written. The messages have to be checked against their xsd-schema and if valid the product can be used.

Results per KPA

N/A.

F.7.2 Analysis of Exercise #06 Results per Technical Validation objective

Witnessed by using webex, METForTAM service message PolygonWeatherTypes was first filled by input from LDO GWMS default product and then by DLR RadTRAM product.

LDO demonstrated three screens: one is showing processes running, other two show one subscriber each who subscribed the messages (one for console output, other for writing output into log-files). Processes include emulation of LDO raw Radar and Lightning data (from a campaign conducted in SESAR 1 at Braunschweig airport [53] for the historical time window 2015-04-01T13:00:00Z - 2015-04-01T14:00:00Z), GWMS default product generation for convection, the METForTAM publisher, an internal and an external AMQP broker and the RadTRAM process. The latter polls the DLR web server and gets RadTRAM xml data via https that are being emulated for the same historical time frame as the one emulated by LDO, but for all of Germany. Data flow and processing are shown in Figure 35.

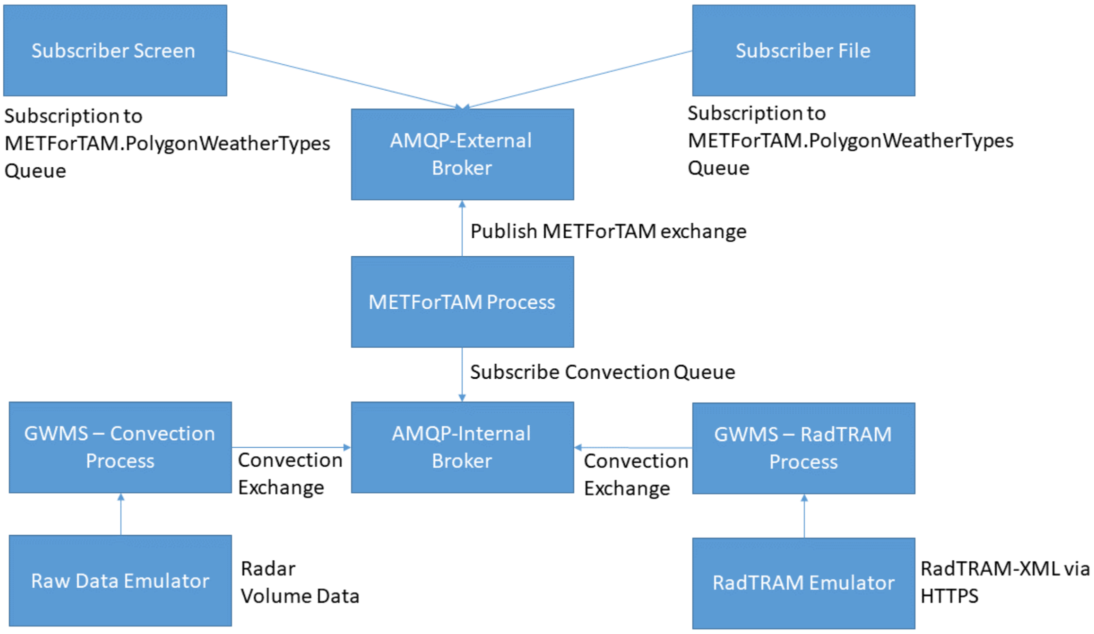

Figure 35: Flow chart illustrating data flow and processing for two different inputs used in exercise.

OBJ-18-04b-TRL6-TVALP-011 Results

CRT-18-04b-TRL6-TVALP-011.001: Connection to second provider is successfully established.

Prior the Validation exercise the connection was already tested, data retrieved and the converter written to fit the data elements of the PolygonWeatherTypes message within the METForTAM service.

During the validation exercise itself the RadTram process established connection to DLR URL and took the latest available file and transferred it into message immediately. This worked without any problem for the complete one-hour run as well.

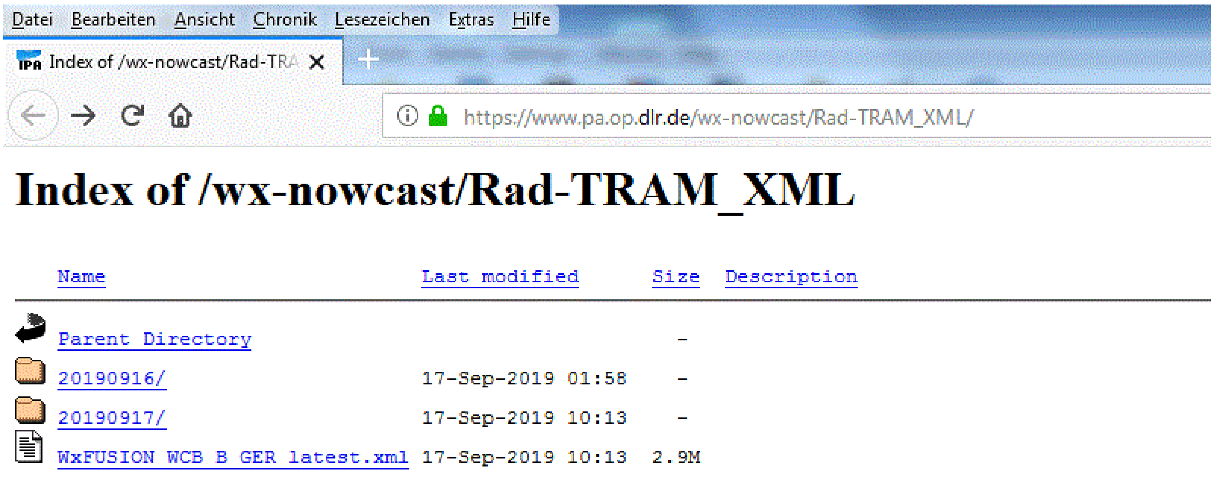

Figure 36: HTTPS interface of DLR where latest emulated data is stored.

All other previously generated files are within the folder “20190917” named by date.

CRT-18-04b-TRL6-TVALP-011.002: METForTAM service is correctly provided with GWMS proprietary convection algorithm.

First run is done with LDO product, and METForTAM service with PolygonWeatherTypes is started; AMQP broker as substitute for a real SWIM node distributes messages via Queues compliant to the METForTAM service interface. Subscribers that write to screen for visual control and log-file (validation_LDO.log) for later analysis are started; then emulation of data is started.

Output on console: first message is generated as xml-file with convection polygon coordinates (normally turbulence and precipitation cells are also included, but are both empty since we use only convection in exercise). Log-file is written as well. Emulation of LDO data was stopped after two messages have been generated after the input data was available from the emulator. Subscription was stopped accordingly. Later the complete one-hour run was executed and the output can be seen for timestep T0 (13:00UTC) and all forecast time steps in Figure 37.

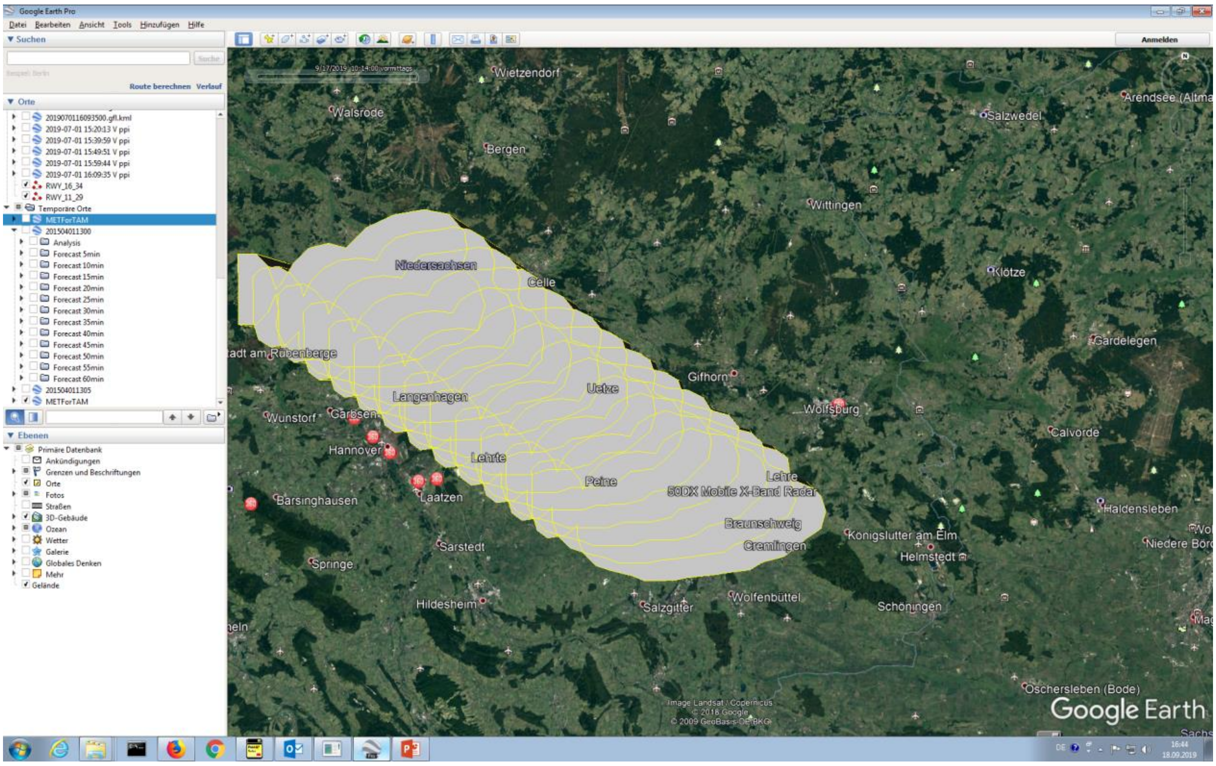

Figure 37: METForTAM output for WATSTORM input (LEONARDO), T0 plus all forecast time steps included.

CRT-18-04b-TRL6-TVALP-011.003: METForTAM service is successfully swapped to new input using RadTRAM convection algorithm

Subscription started again for two subscribers (one for console output, one into file validation_DLR.log). Emulation of data by process RadTram started. Output on console and files simultaneously: took the latest file on DLR URL and transferred it into message immediately. The differences of DLR product is that it covers Germany completely; LDO takes only data collected by Radar at Braunschweig airport (measurement campaign during SESAR 1 [53]). In addition, DLR applies two colours for different dBZ thresholds.

As for the run with GWMS proprietary data, the subscription was only executed after two or three outputs have been generated. Then it was stopped and later a complete one-hour run was started. Below in Figure 38 and Figure 39, respectively, you can see the original input and the output of METForTAM. They are identical despite the different coloring of some of the deteted and tracked cells from the original RadTRAM input.

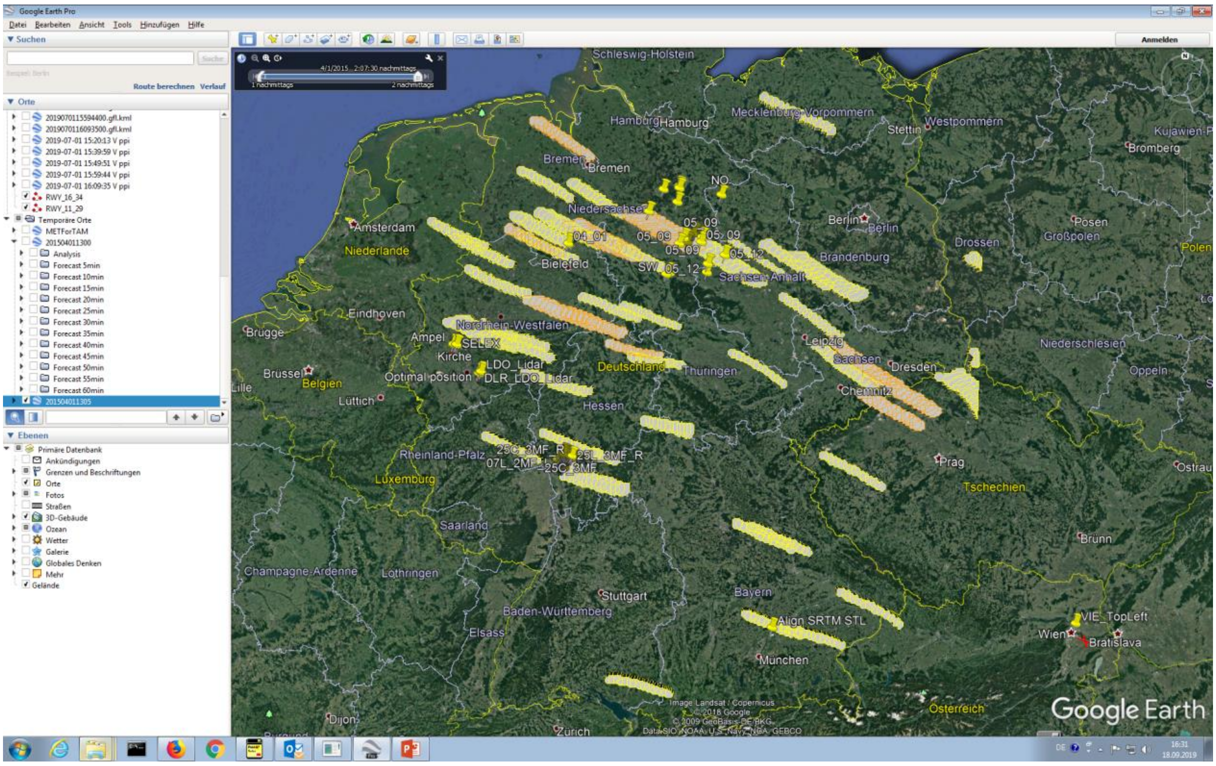

Figure 38: Screenshot of detected and forecasted convection cells by RadTRAM (>37dBZ) for 1st April 2015, 13:05UTC.

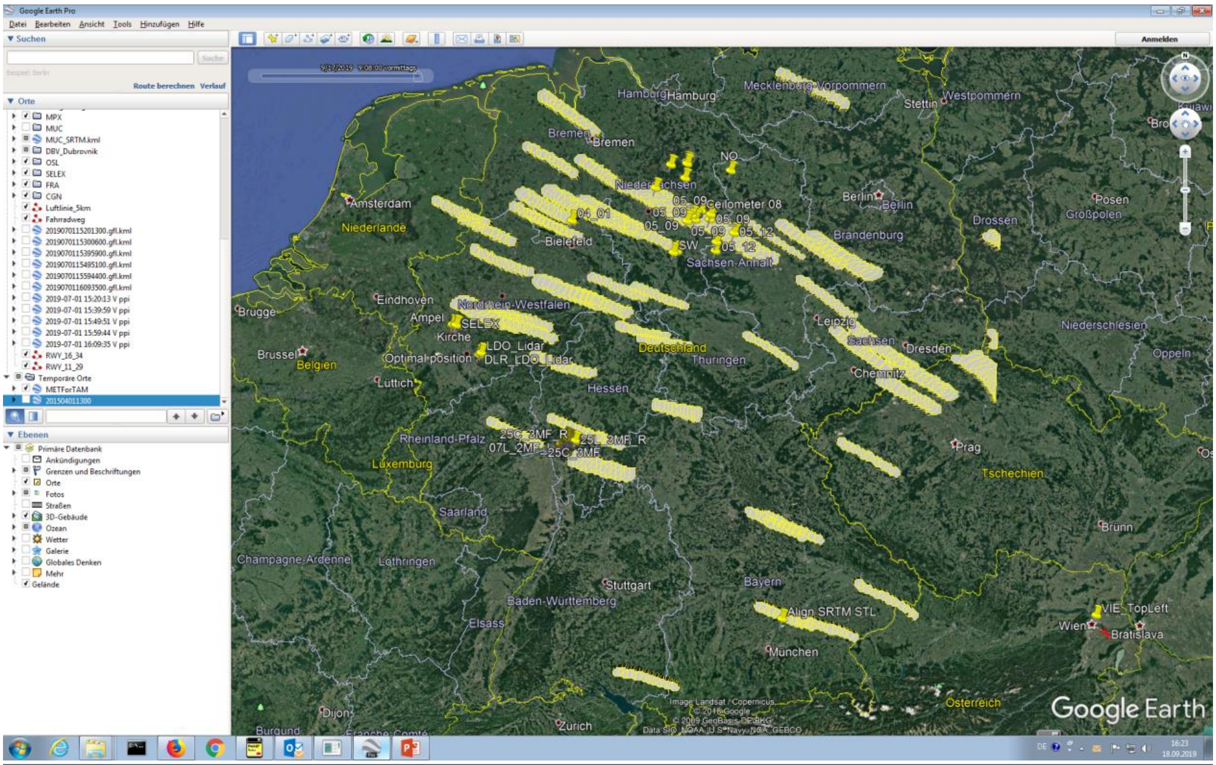

Figure 39: METForTAM output for RadTRAM input, for 1st April 2015, 13:05UTC; equivalent to Figure above.

<u>**CRT-18-04b-TRL6-TVALP-011.004: Gaps in convection product data elements within METForTAM service are documented**</u>

During validation exercise witnessed by participants, only for two consecutive messages the demonstration was done. Afterwards, the run for one hour was started for both data sources, respectively, to compare later the messages.

Below the mapping table shows the data elements included in METForTAM service and the mapping to RadTRAM objects. The design of both input sources foresee all detected convection objects in one file for up to 60 min in five minute forecast steps. Two features could not be mapped, those are:

- number of lightning strokes (RadTRAM provides only classification of lightning if moderate or severe)
- hail intensity

The METForTAM service foresees also that protected areas are checked if cells violate this area. Also the type and alignment of cells to each other can be determined. But this was not included in the RadTRAM of DLR nor in the current thunderstorm product WATSTORM of LEONARDO Germany GmbH. One additional difference worth mentioning is, that the WATSTORM product includes lightning data as criteria for cell detection. So, a thunderstorm cells has to include lightning be definition together with the detected convection cell based on dBZ thresholds.

In general, we have a very good compliance of both input sources.

Mapping RadTRAM <-> METForTAM Convection Objects (polygon weather types)		
Mapping - : No + : Yes	Leonardo (METForTAM)	DLR (RadTRAM)
ConvectionObjects		
-	no protected area / no violation check	No
+	all convection cells for several time steps in one file	Yes
+	time steps 0min up to 60min in five minute forecast steps	Yes
-	no TypeandAlignmentTS	No
-	lightning (counting)	No
ConvectionCell		
+	cell:GM_polygon	gml:posList
+	direction	wims: movingDirection
-	hailintensity	No
+	precipitation intentsity	10^(maxReflectivity/(10*1.4))/300 [mm/h]
+	speed	wims: movingSpeed
4DPointValue		
+	startValidity	ValidityStartTime
+	endValidity	ValidityEndTime
+	startLifetime	ValdityStartTime - ForecastTime
+	endLifetime	RefreshTime
+	isMeasurement	ForecastTime == 0 (in <forecastSet>)
ConvectionTimeSteps		
+	convectionTimeSteps	forecastSet of type ForecastSet

Table 14: Mapping of METForTAM elements to RadTRAM input

Below the output of the METForTAM service is plotted, once with LEONARDO and once with DLR RadTRAM input. We compare cells within vicinity of Braunschweig only since the input data of LEONARDO has limited range of one X-band radar installed at the airport.

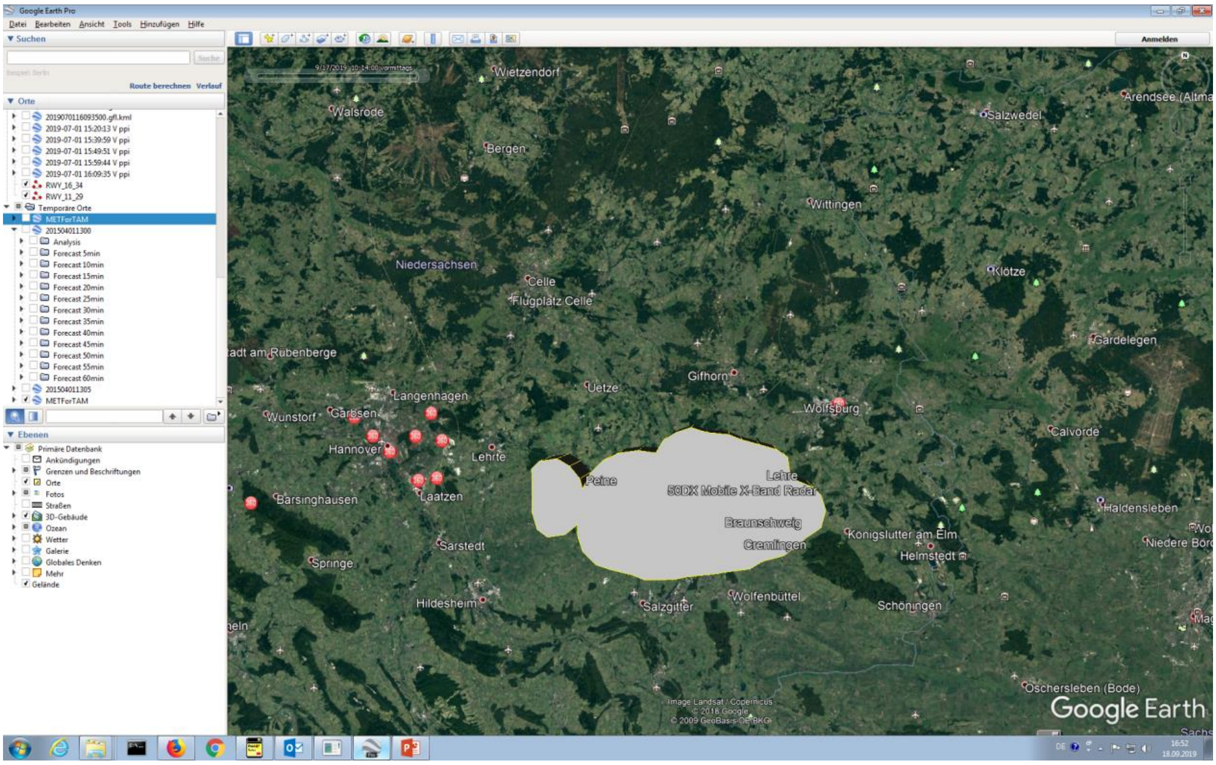

Figure 40: METForTAM output for WATSTORM input (LEONARDO), T0+60 min forecast time step.

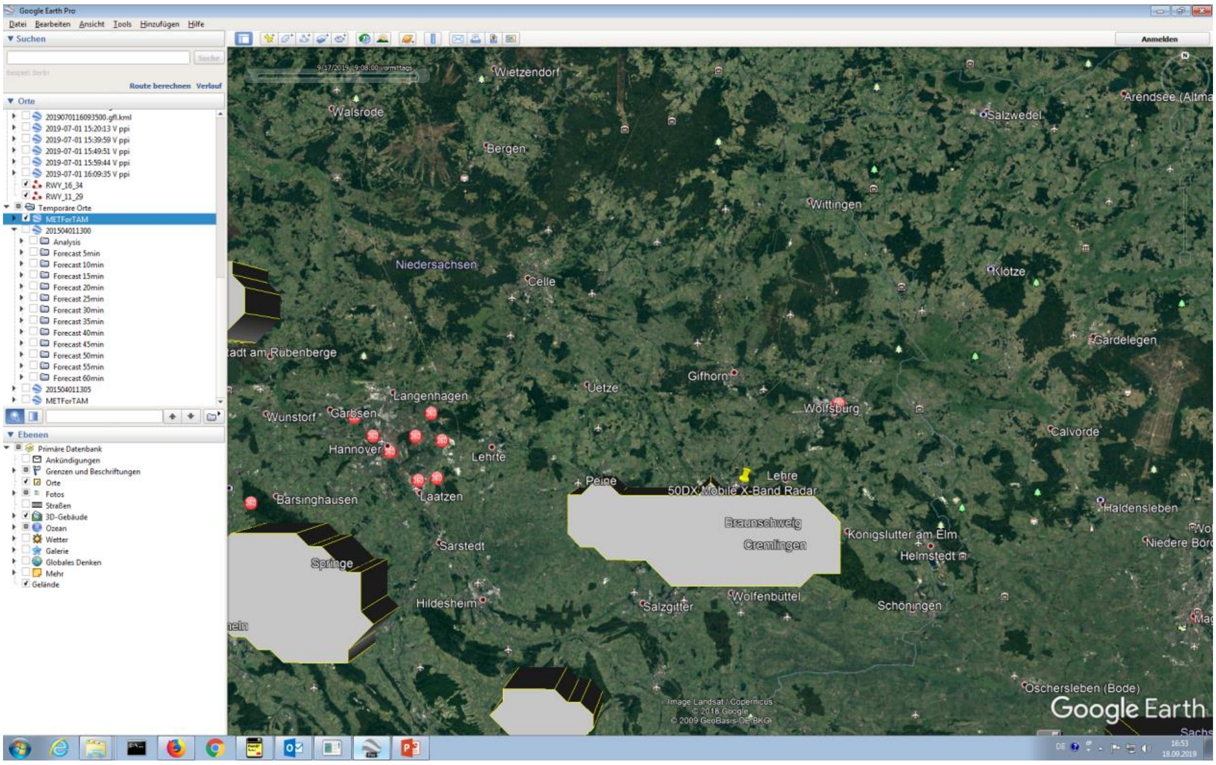

Figure 41: METForTAM output for RadTRAM input (DLR), T0+60 min forecast time step.

Convection cells close to Braunschweig are detected by both algorithms. The polygon number and shape differs because of different criteria for polygon definition. Reasons are different dBZ thresholds (RadTRAM >37dBZ, WATSTORM >42dBZ) for cell detection, and WATSTORM includes lightning as criteria for qualifying as thunderstorm cell. In addition, the derived speed and direction of cells may differ. Therefore, the forecasted cells are different in shape and location. In general, we have a good correlation between the two outputs for the complete one-hour run.

F.7.3 Unexpected Behaviours/Results

No unexpected behaviours or results occurred.

F.7.4 Confidence in Results of Validation Exercise #06

Level of significance/limitations of Technical Validation Exercise Results

The exercise demonstrated the capability to accept input from another MET service provider than the default one. This capability can be generalised and applied to any product GWMS is providing and demonstrates the service oriented architecture where the MET data provider can be different but the GWMS provides the service as requested. Nevertheless, it was tested only for the convection product within the METForTAM service and here only for the thunderstorm cells excluding turbulence and precipitation cells.

Limitations are that maybe not all data elements can be filled if the respective MET provider is not providing all the input data that is included in the service design. In addition, a mapping of the elements is prerequired, followed by writing a converter to fill the service accordingly. Checking the new content against their xsd-schema is also very useful to be sure to receive valid messages.

Quality of Technical Validation Exercises Results

All precondition have been carefully checked and prepared, so that execution of the validation went very smoothly and the quality can be regarded as good.

Significance of Technical Validation Exercises Results

The exercise was run only once for approximately one hour since no factors will change during any repetition of it. Important was that the new input was retrieved and transferred into the METForTAM service during the complete period. During the one-hour run the payload messages differ of course, because of the different weather phenomena captured. In addition, the results are only representative for the convection product within the service.

F.7.5 Conclusions

Conclusions on technical feasibility

The switch from one MET service provider to another one is fully feasible after pre-conditions have been considered. Pre-conditions are mapping of data elements and writing a converter to match data elements, which may have other names.

Conclusions on performance assessments

N/A

F.7.6 Recommendations

No specific recommendations exist for this exercise explicitly. Nevertheless, other MET service providers and their input could be tested for message payloads other than the convection product.

For providing full comparison possibilities, the cell detection algorithms have to be aligned using same dBZ thresholds and either excluding or including the lightning feature.

Appendix G Validation Exercise EXE-18-04b-TRL4-001_LPS SR “Remote Tower MET Service” Report

G.1 Summary of the Validation Exercise Plan

G.1.1 Validation Exercise description, scope

In the scope of this verification is the TRL4 prototype of Remote Tower MET Service. It has been designed to comply with technical requirements [39]. These technical requirements originally come from Solution Pj.05-05 Advanced Automated MET System. Pj.18-04b has been asked to support Solution Pj.05-05 Advanced Automated MET System validated in Q3/2018 in Poprad. Due to schedule constraints this service could not be validated within PJ.05-05 validation exercise and therefore it has been decided during progress meetings, that in such case this service will be validated in scope of Pj.18-04b as internal validation exercise with all relevant documentation under Pj.18-04b.

The Remote Tower MET Service addresses dependency with PJ.05-05 ‘Advanced Automated MET System’ in order to provide all input data necessary for enhanced automated weather observation at the airport in a standardized way (especially Airport Integrated Camera Images – new capability developed also within the scope of Pj18-04b Appendix I which has not been addressed yet. The input data can be split into 2 basic groups, which the payload creating system has to encode:

- Integrated dual VIS/IR airport camera imagery
- Other Measured/sensed data at the airport

The main purpose of the validation exercise is to test the prototype functions against the given technical requirements [39].

G.1.2 Summary of Validation Exercise Validation Objectives and success criteria

[OBJ]

Identifier	OBJ-18-04b-TRL4-TVALP-014
Objective	To validate that the Remote Tower MET Service is being correctly provided.
Title	Remote Tower MET Service provision
Category	<technical feasibility>
Key environment conditions	Nominal and adverse weather conditions
TRL Phase	TRL4

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-IS1.0040

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL4-TVALP-014.001	The Remote Tower MET Service is correctly provided to airport stakeholders.

G.1.3 Summary of Validation Exercise Validation scenarios

Reference scenario

Data are shared in non-standardized way (not as a SWIM service) using synchronization scripts and proprietary data communication.

Solution Scenario(s)

All information from Advanced Automated MET System (developed in PJ.05-05) is provided by Remote Tower MET service in the required update rate.

Payload

The web services communicate using the Extensible Markup Language (XML). XML is a markup language that can be used to encode data in a human and machine-readable format. It is defined by the World Wide Web Consortium's XML 1.0 Specification and several other open standards. To define the structure and the content of the XML documents XML Schema Definition (XSD) is used. XSD is used to express a set of rules to which the XML documents must conform.

Web service

The web services are implemented using the Simple Object Access Protocol (SOAP). This protocol uses XML Information Set as a message format. The application layer protocol used is HTTP with an encrypted transport protocol (TLS).

The web service is described by the Web Services Description Language (WSDL). A client connecting the web service can use the WSDL to determine what operations are available on the server. The datatypes are described in the form of XSD. This information enables the client to call the operations listed in the WSDL using XML over HTTPS.

The web services use the Publish/Subscribe Push Message Exchange Pattern (MEP). The client of the web service subscribes to receive the data using the subscribe operation. When data is available the publisher sends the data to the subscribed clients. The client can unsubscribe using the unsubscribe operation.

The back-end is implemented using the Java programming language.

Communication protocol

The protocol used to communicate with the web service is SOAP, which uses HTTP as an application layer protocol, TLS encrypted TCP as a transport layer protocol and IP as a network layer protocol.

G.1.4 Summary of Validation Exercise Validation Assumptions

No assumption was identified for this exercise.

G.2 Deviation from the planned activities

No deviation was identified for this exercise.

G.3 Validation Exercise Results

G.3.1 Summary of Validation Exercise Results

The following table summarises the results of the Validation Exercise EXE-18-04b-TRL4-001_LPS SR “Remote Tower MET Service” compared to the success criteria identified within the Technical Validation Plan per validation objective.

Results obtained are assessed against the success criteria and considering the characteristics of the simulation in order to decide if the Validation Objective Analysis Status is OK, partially OK, NOK or Not Applicable (N/A).

The following nomenclature has been used:

- OK
    - Validation objective achieves the expectations
- NOK

    - Validation objective does not achieve the expectations
- Partially OK
    - Validation objectives does not fully achieves the expectation
- N/A
    - Validation objectives out of scope of the validation exercise (in compliance with TVALP)

More detailed results (per validation objective) are then described in section G.3.2.

Validation Exercise Validation Objective ID	Validation Exercise Validation Objective Title	Validation Exercise Success Criterion ID	Validation Exercise Success Criterion	Sub-operating environment	Exercise Validation Results	Validation Exercise Validation Objective Status
OBJ-18-04b-TRL4-TVALP-014	Remote Tower MET Service provision	CRT-18-04b-TRL4-TVALP-014.001	The Remote Tower MET Service is correctly provided to airport stakeholders.	N/A	Data sent using the Remote Tower MET Service and data received from the service are the same so the service does not deteriorate quality of data.	OK

Table 15:Validation Results for EXE-18-04b-TRL4-001_LPS SR "Remote Tower MET Service"

G.3.2 Analysis of Exercise Results per Validation objective

OBJ-18-04b-TRL4-TVALP-014 Results

The aim of validation objective OBJ-18-04b-TRL4-TVALP-015 (Remote Tower MET Service provision) is to validate that the Remote Tower MET Service is capable of providing to Advanced Automated MET System along with data from standard MET sensors also images from both visible and infrared camera (with SWIM dissemination functionality). These camera images significantly enhance current scope of automated weather observation of prevailing visibility, aeronautically significant weather phenomena and clouds. Currently these automatically observed weather elements are reported in simplified form only and some are omitted completely. In addition, the images from cameras can support human MET Observer in observation of some weather parameters suffering from observer´s subjectivity and thus enhances quality of weather observation in general.

RemoteTWRMET web service has been developed as described in Solution scenario in compliance with Information Service Modelling Guidelines [8] and modelled [39]. Context diagrams containing RemoteTWRMET Service are in PJ.18-04b TS/IRS [39].

In laboratory test condition has been proved that data sent using the Remote Tower MET Service (RemoteTWRMET service) and data received from the service are the same so the service does not deteriorate quality of data.

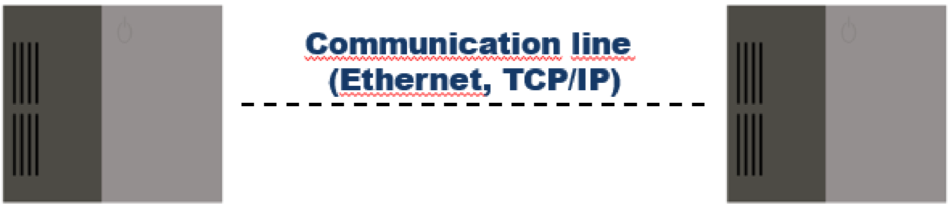

Figure 42:RemoteTWRMET service validation exercise scheme

G.3.3 Unexpected Behaviours/Results

No unexpected behaviour/results were recorded during the validation.

G.3.4 Confidence in Results of Validation Exercise

Level of significance/limitations of Validation Exercise Results

RemoteTWRMET Service was not implemented in operational Solution. Only laboratory test was performed as is the aim of TRL4 maturity level.

Quality of Validation Exercises Results

Verification process is documented in respective Availability Note [72].

Significance of Validation Exercises Results

As mentioned in limitations, services were not implemented in dependent Solution. Only laboratory test was performed. The significance can be limited because isolated local network was used.

G.3.5 Conclusions

The service is technically feasible and ready to support related Solution. The service does not deteriorate quality of data (data sent using the service and data received from the service were the same).

G.3.6 Recommendations

It is recommended in next phases to implement service into operational Solution and upgrade it technically to TRL6 maturity.

Appendix H Validation Exercise EXE-18-04b-TRL4-002_LPS SR "Runway Weather Monitoring and Forecast Services (input/output)" Report

H.1 Summary of the Validation Exercise Plan

H.1.1 Validation Exercise description, scope

In the scope of this validation exercise is the TRL4 prototype of Runway Weather Monitoring and Forecast Services (input/output). It has been designed to comply with technical requirements [39]. Pj.18-04b has been asked to support Solution Pj.03b-06 Safety Support Tool for runway excursions in order to meet following operational requirements:

- REQ-03b.06-SPRINTEROP-ATSS.0009 (RCAMS input data SWIM compliance) - each data provided to RCAMS for the runway surface condition computation should be compatible with SWIM.
- REQ-03b.06-SPRINTEROP-ATSS.0010 (RCAMS output data SWIM compliance) - all RCAMS output dissemination should be supported by SWIM. This means: Predicted RWYCC, RCR, Runway Surface Condition, Runway Surface Condition Trend assessment.

Due to schedule constraints Runway Weather Monitoring and Forecast Services (input/output) could not be validated within PJ.03b-06 validation exercises and therefore it has been decided during progress meetings, that in such case these services will be validated in scope of Pj.18-04b as internal validation exercise with all relevant documentation under Pj.18-04b.

The Runway Weather Monitoring and Forecast Services (input/output) addresses dependency with PJ.03b-06 'Safety Support Tools for runway excursions' in order to provide required input data necessary for RCAMS (input service) and disseminate outputs from RCAMS in a standardized way, which has not been addressed yet. The input data can be split into 4 basic groups, which the payload creating system has to encode:

- Measurements from surface condition sensors
- Measurements from MET sensors
- Braking action/Computed braking action (from OBACS) data
- Weather condition forecast

On the other hand, output data are consolidated into Runway condition report (RCR) to be disseminated to all interested stakeholders.

The main purpose of the validation exercise is to test the prototype functions against the given technical requirements [39].

H.1.2 Summary of Validation Exercise Validation Objectives and success criteria

[OBJ]

Identifier	OBJ-18-04b-TRL4-TVALP-0012
Objective	To validate that the Runway Weather Monitoring and Forecast Service (input) -RWYWeather is capable of providing all the required data (with SWIM dissemination functionality) for RCAMS system (AWOS, ground sensor, etc.)
Title	Runway Weather Monitoring and Forecast Service (input) - RWYWeather provision
Category	<technical feasibility>
Key environment conditions	Nominal and adverse weather conditions
TRL Phase	TRL4

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-IS1.0030

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL4-TVALP-012.001	The service is providing all the data used for PJ.03b-06 validation.
CRT-18-04b-TRL4-TVALP-012.002	Maximal delay resulting from service use is no greater than 3 min.
CRT-18-04b-TRL4-TVALP-012.003	The data can be disseminated in SWIM format.

[OBJ]

Identifier	OBJ-18-04b-TRL4-TVALP-013
Objective	To validate that the Runway Weather Monitoring and Forecast Service (output) is able to disseminate RCR as well as any additional information generated by RCAMS system.

Title	Runway Weather Monitoring and Forecast Service (output) provision
Category	<technical feasibility>
Key environment conditions	Nominal and adverse weather conditions
TRL Phase	TRL4

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-IS1.0031

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL4-TVALP-013.001	The service is handling dissemination of RCR according to new ICAO regulations[4]
CRT-18-04b-TRL4-TVALP-013.002	The service is handling dissemination of any additional relevant material (e.g. Predicted RCR as proposed by PJ.03b-06)

[4] link to ICAO documents:

Procedures for Air Navigation Services — Aerodromes (PANS-Aerodromes) – 2nd edition – ICAO Doc 9981 – 2016.

Annex 14 to the Convention on International Civil Aviation (Aerodromes), Volume I – Aerodrome Design and Operations, 7th edition – ICAO – July 2016.

Annex 15 to the Convention on International Civil Aviation (Aeronautical Information Services), 15th edition – ICAO – July 2016.

H.1.3 Summary of Validation Exercise Validation scenarios

Reference scenario

Data are shared in non-standardized way (not as a SWIM service) using synchronization scripts and proprietary data communication.

Solution Scenario(s)

All information from RCAMS System (developed in PJ.03b-06) is provided by Runway Weather Monitoring and Forecast services (input/output).

Payload

The web services communicate using the Extensible Markup Language (XML). XML is a markup language that can be used to encode data in a human and machine-readable format. It is defined by the World Wide Web Consortium's XML 1.0 Specification and several other open standards. To define the structure and the content of the XML documents XML Schema Definition (XSD) is used. XSD is used to express a set of rules to which the XML documents must conform.

Web service

The web services are implemented using the Simple Object Access Protocol (SOAP). This protocol uses XML Information Set as a message format. The application layer protocol used is HTTP with an encrypted transport protocol (TLS).

The web service is described by the Web Services Description Language (WSDL). A client connecting the web service can use the WSDL to determine what operations are available on the server. The datatypes are described in the form of XSD. This information enables the client to call the operations listed in the WSDL using XML over HTTPS.

The web services use the Publish/Subscribe Push Message Exchange Pattern (MEP). The client of the web service subscribes to receive the data using the subscribe operation. When data is available the publisher sends the data to the subscribed clients. The client can unsubscribe using the unsubscribe operation.

The back-end is implemented using the Java programming language.

Communication protocol

The protocol used to communicate with the web service is SOAP, which uses HTTP as an application layer protocol, TLS encrypted TCP as a transport layer protocol and IP as a network layer protocol.

H.1.4 Summary of Validation Exercise Validation Assumptions

No assumptions was identified for this exercise.

H.2 Deviation from the planned activities

No deviation was identified for this exercise.

H.3 Validation Exercise Results

H.3.1 Summary of Validation Exercise Results

The following table summarises the results of the Validation Exercise EXE-18-04b-TRL4-002_LPS SR "Runway Weather Monitoring and Forecast Services (input/output)" compared to the success criteria identified within the Technical Validation Plan per validation objective.

Results obtained are assessed against the success criteria and considering the characteristics of the simulation in order to decide if the Validation Objective Analysis Status is OK, partially OK, NOK or Not Applicable (N/A).

The following nomenclature has been used:

- OK
  - Validation objective achieves the expectations
- NOK
  - Validation objective does not achieve the expectations
- Partially OK
  - Validation objectives does not fully achieves the expectation
- N/A
  - Validation objectives out of scope of the validation exercise (in compliance with TVALP)

Validation Exercise Validation Objective ID	Validation Exercise Validation Objective Title	Validation Exercise Success Criterion ID	Validation Exercise Success Criterion	Sub-operating environment	Exercise Validation Results	Validation Exercise Validation Objective Status
OBJ-18-04b-TRL4-TVALP-0012	Runway Weather Monitoring and Forecast Service (input) – RWYWeather provision	CRT-18-04b-TRL4-TVALP-012.001	The service is providing all the data used for PJ.03b-06 validation	N/A	Data sent using the Runway Weather Monitoring and Forecast Service (input) (RWYWeather service) and data received from the service are the same so the service does not deteriorate quality of data.	OK
		CRT-18-04b-TRL4-TVALP-012.002	Maximal delay resulting from service use is no greater than 3 min.			OK
		CRT-18-04b-TRL4-	The data can be disseminated			OK

		TVALP-012.003	in SWIM format.			
OBJ-18-04b-TRL4-TVALP-013	Runway Weather Monitoring and Forecast Service (output) provision	CRT-18-04b-TRL4-TVALP-013.001	The service is handling dissemination of RCR according to new ICAO regulations.[5]		Data sent using the Runway Weather Monitoring and Forecast Service (output) and data received from the service are the same so the service does not deteriorate quality of data. However, dissemination of full time series of Predicted RWYCC were not addressed.	OK
		CRT-18-04b-TRL4-TVALP-013.002	The service is handling dissemination of any additional relevant material (e.g. Predicted RCR as proposed by PJ.03b-06).			Partially OK

More detailed results (per validation objective) are then described in section H 3.2.

Table 16: Validation Results for EXE-18-04b-TRL4-002_LPS SR "Runway Weather Monitoring and Forecast Services (input/output)"

H.3.2 Analysis of Exercise Results per Validation objective

OBJ-18-04b-TRL4-TVALP-012 Results

The aim of validation objective OBJ-18-04b-TRL4-TVALP-012 (Runway Weather Monitoring and Forecast Service (input) - RWYWeather provision) is to validate that the Runway Weather Monitoring and Forecast Service (input) - RWYWeather is capable of providing all the required data (with SWIM dissemination functionality) for RCAMS system (AWOS, ground sensor, etc.).

[5] Procedures for Air Navigation Services — Aerodromes (PANS-Aerodromes) – 2nd edition – ICAO Doc 9981 – 2016.

Annex 14 to the Convention on International Civil Aviation (Aerodromes), Volume I – Aerodrome Design and Operations, 7th edition – ICAO – July 2016.

Annex 15 to the Convention on International Civil Aviation (Aeronautical Information Services), 15th edition – ICAO – July 2016.

RWYWeather web service has been developed as described in H.1.3 (Solution scenario) in compliance with Information Service Modelling Guidelines [8] and modelled [39]. Context diagrams containing RWYWeather Service are in PJ.18-04b TS/IRS [39].

The XSD files for required input data for RCAMS system have been created (AWOS, runway built-in sensors, OBACS system). AWOS data contains observations of basic meteorological parameters (Air temperature, humidity, pressure, precipitation type and amount, etc.) characterizing current weather at the airport. Some of these parameters directly affects runway surface condition, therefore they were used as an input for RWYCC calculation. Runway built-in sensors provide data about runway surface (ground temperature, freezing point temperature, water film depth and estimated contaminant type). These data come directly from runway and are very important for RCAMS system to determine runway surface condition status. OBACS system is installed at an aircraft. When OBACS-equipped aircraft lands at the airport, it provides objective braking performance data applicable as downgrade criteria in RWYCC calculation.

In laboratory test condition has been proved that data sent using the Runway Weather Monitoring and Forecast Service (input) (RWYWeather service) and data received from the service are the same so the service does not deteriorate quality of data.

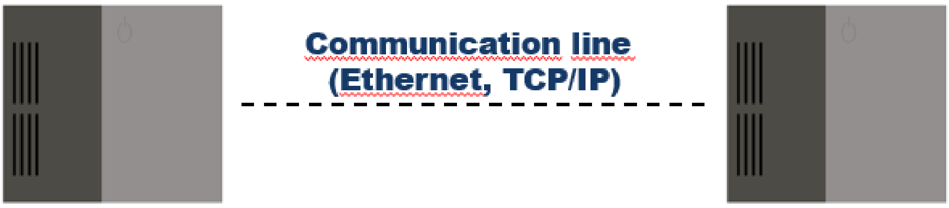

Figure 43: RWYWeather service validation exercise scheme

OBJ-18-04b-TRL4-TVALP-013 Results

The aim of validation objective OBJ-18-04b-TRL4-TVALP-013 (Runway Weather Monitoring and Forecast Service (output) provision) is to validate that the Runway Weather Monitoring and Forecast Service (output) is able to disseminate output generated by RCAMS system (RCR). Runway condition report (RCR) is a standardized message describing runway surface condition. It contains information about contaminant coverage, contaminant type and depth and resulting RWYCC code per each third of specific runway in compliance with new GRF format. In addition, it may contain further optional awareness sections regarding contamination on other areas (apron, taxiway), reduced width of runway, snowbanks, runway treatment etc. which supports decision making of pilot during landing or take off. RCR created by Airport Operator is disseminated to the ATCO, who shares these information with pilots.

Runway Weather Monitoring and Forecast Service (output) web service has been developed as described in H. 1.3 (Solution scenario) in compliance with Information Service Modelling Guidelines [8] XSD files for output from RCAMS system have been created (RCR). In laboratory test condition has been proved that data sent using the Runway Weather Monitoring and Forecast Service (output) and data received from the service are the same so the service does not deteriorate quality of data.

H.3.3 Unexpected Behaviours/Results

No unexpected behaviour/results were recorded during the validation.

H.3.4 Confidence in Results of Validation Exercise

Level of significance/limitations of Validation Exercise Results

Neither RWYWeather service (Runway Weather Monitoring and Forecast Input Service) nor Runway Weather Monitoring and Forecast Output Service was implemented in operational Solution. Only laboratory test was performed as is the aim of TRL4 maturity level.

Runway Weather Monitoring and Forecast Service (output) has not been modelled yet.

Quality of Validation Exercises Results

Verification process is documented in respective Availability Note [73].

Significance of Validation Exercises Results

As mentioned in limitations, services were not implemented in operational Solution. Only laboratory test was performed. The significance can be limited because isolated local network was used.

H.3.5 Conclusions

The services are technically feasible and ready to support related operational Solution. Both services do not deteriorate quality of data (data sent using the service and data received from the service were the same).

H.3.6 Recommendations

It is recommended in next phases to implement services into operational Solution, upgrade them technically to TRL6 maturity and complete missing modelling of service "Runway Weather Monitoring and Forecast Service (output)" as well as complete its implementation with Predicted RWYCC and Runway Condition Trend assessment elements.

Appendix I Validation Exercise EXE-18-04b-TRL4-003_LPS SR "Airport MET Camera" Report

I.1 Summary of the Validation Exercise Plan

I.1.1 Validation Exercise description, scope

In the scope of this validation exercise is the TRL4 prototype of the Airport integrated dual camera. It has been improved and adjusted to comply with technical requirements [39]. These technical requirements originally come from Solution Pj.05-05 Advanced Automated MET System. Pj.18-04b has been asked to support validation exercise of that solution from 08/2018 to 10/2018 in Poprad by the prototype development.

The integrated camera captures both standard "visible" (VIS) and infrared (IR) video streams. Camera can be rotated around horizontal and vertical axes. To serve airport MET purposes, a camera driver and pre-processor must perform the following tasks:

- Automatically schedule observational scans of in cycles with reasonable frequency, presumably not lower than a scan each 10 minutes
- Avoid prolonged direct "looking" in current sun position during sky scans, to avoid early aging of camera elements and lower image quality
- Extract imagery from the video streams
- Combine images from elevations 0 to +90 degrees and azimuths 0 to 360 degrees into one full sky image (the so called "stitching" process)
- Extract 360 degree horizontal view (horizontal panorama) presumably at higher resolution
- Extract short videos (5-10 sec) for phenomena recognition at regular intervals.

Moreover human faces and car identification plates shall be blurred/removed from pictures.

The major benefit of using Airport integrated dual camera to SESAR and the ATM community is:

- Enhancement of MET awareness for AO, ATCO, AU (even without human MET observer, where not present)
- Support of MET Observer (even at remote location) in current weather observations

The main purpose of the validation exercise is to test the prototype functions against the given technical requirements [39] and validate that visible light/IR camera can provide valuable inputs to detection of cloud/ visibility/phenomena at an Airport.

I.1.2 Summary of Validation Exercise Validation Objectives and success criteria

[OBJ]

Identifier	OBJ-18-04b-TRL4-TVALP-015
Objective	To validate that visible light/IR camera can provide valuable inputs to detection of cloud/visibility/phenomena at an Airport.
Title	Airport MET Camera Imagery
Category	<technical feasibility>
Key environment conditions	Small airports, various weather conditions
TRL Phase	TRL4

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	REQ-18-04b-TS-CC42.0060 REQ-18-04b-TS-CC42.0070 REQ-18-04b-TS-CC42.0080 REQ-18-04b-TS-CC42.0090 REQ-18-04b-TS-CC42.0100 REQ-18-04b-TS-CC42.0110

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL4-TVALP-015.001	Camera provided series of stitched all sky imagery suitable for automatic recognition and remote observer observation of clouds.
CRT-18-04b-TRL4-TVALP-015.002	Camera provided series of visibility landmarks imagery suitable for automatic recognition and remote observer observation of prevailing visibility.
CRT-18-04b-TRL4-TVALP-015.003	Camera provided video sequences of phenomena.

I.1.3 Summary of Validation Exercise Validation scenarios

Reference scenario

Aeronautically significant clouds, weather phenomena and prevailing visibility with directional variations are observer by locally sited human observers.

Solution Scenario(s)

Pictures of whole sky and significant clouds, videos of weather phenomena and pictures of prevailing visibility points in all directions are captured by camera in both visible and infrared (only for clouds) wavelength bands. Site Acceptance Test has been performed to prove prototype´s functionalities.

I.1.4 Summary of Validation Exercise Validation Assumptions

No assumptions was identified for this exercise.

I.2 Deviation from the planned activities

No deviation was identified for this exercise.

I.3 Validation Exercise Results

I.3.1 Summary of Validation Exercise Results

The following table summarises the results of the Validation Exercise EXE-18-04b-TRL4-003_LPS SR "Airport MET Camera" compared to the success criteria identified within the Technical Validation Plan per validation objective.

Results obtained are assessed against the success criteria and considering the characteristics of the simulation in order to decide if the Validation Objective Analysis Status is OK, partially OK, NOK or Not Applicable (N/A).

The following nomenclature has been used:

- OK
  - Validation objective achieves the expectations
- NOK
  - Validation objective does not achieve the expectations
- Partially OK
  - Validation objectives does not fully achieves the expectation
- N/A
  - Validation objectives out of scope of the validation exercise (in compliance with TVALP)

More detailed results (per validation objective) are then described in section G.3.2.

Validation Exercise	Validation Exercise Validati	Validation Exercise	Validation Exercise	Sub-operating environment	Exercise Results	Validation	Validation Exercise

Validation Objective ID	on Objective Title	Success Criterion ID	Success Criterion			Validation Objective Status
OBJ-18-04b-TRL4-TVALP-015	Airport MET Camera Imagery	CRT-18-04b-TRL4-TVALP-015.001	Camera provided series of stitched all sky imagery suitable for automatic recognition and remote observer observation of clouds.	APT Small	The camera rotates and tilts in regular way and takes picture in all directions and elevations to cover half-sphere of sky above the camera. Stitching of pictures is applied in order to obtain one whole sky image projected to the plane.	OK
		CRT-18-04b-TRL4-TVALP-015.002	Camera provided series of visibility landmarks imagery suitable for automatic recognition and remote observer observation of prevailing visibility.		The Camera takes picture of horizon in all cardinal and intercardinal directions with higher resolution to enable identify visibility landmarks by MET Observer or computer-based picture recognition algorithms.	OK
		CRT-18-04b-TRL4-TVALP-015.003	Camera provided video sequences of phenomena.		The camera records regularly in 10 minutes interval short (10 seconds) video of reference area to support recognition of some weather phenomena	OK

Table 17: Validation Results for EXE-18-04b-TRL4-003_LPS SR "Airport MET Camera"

I.3.2 Analysis of Exercise Results per Validation objective

OBJ-18-04b-TRL4-TVALP-015 Results

The aim of validation objective OBJ-18-04b-TRL4-TVALP-015 (Airport MET Camera Imagery) is to validate that visible light/IR camera can provide valuable inputs to detection of cloud/visibility/phenomena at an Airport. The success criteria evaluated in this validation objective has been:

CRT-18-04b-TRL4-TVALP-015.001

For this success criterion, the following hypothesis was postulated: "*Camera provided series of stitched all sky imagery suitable for automatic recognition and remote observer observation of clouds*."

This success criterion has been fulfilled in the following way:

The camera rotates and tilts in regular way and takes picture in all directions and elevations to cover half-sphere of sky above the camera. The same process is applied for VIS and IR camera images. Subsequently all pictures are projected on half-sphere and then from half-sphere to the plane in order to provide whole sky image in 2D (suitable and also for Observer´s display) – see Figure 44. Whole process lasts few minutes as whole sky image is available every 10 minutes. Whole sky images (both VIS and IR) are then prepared for further processing either by computer-based picture recognition algorithms or by human MET Observer with suitable display.

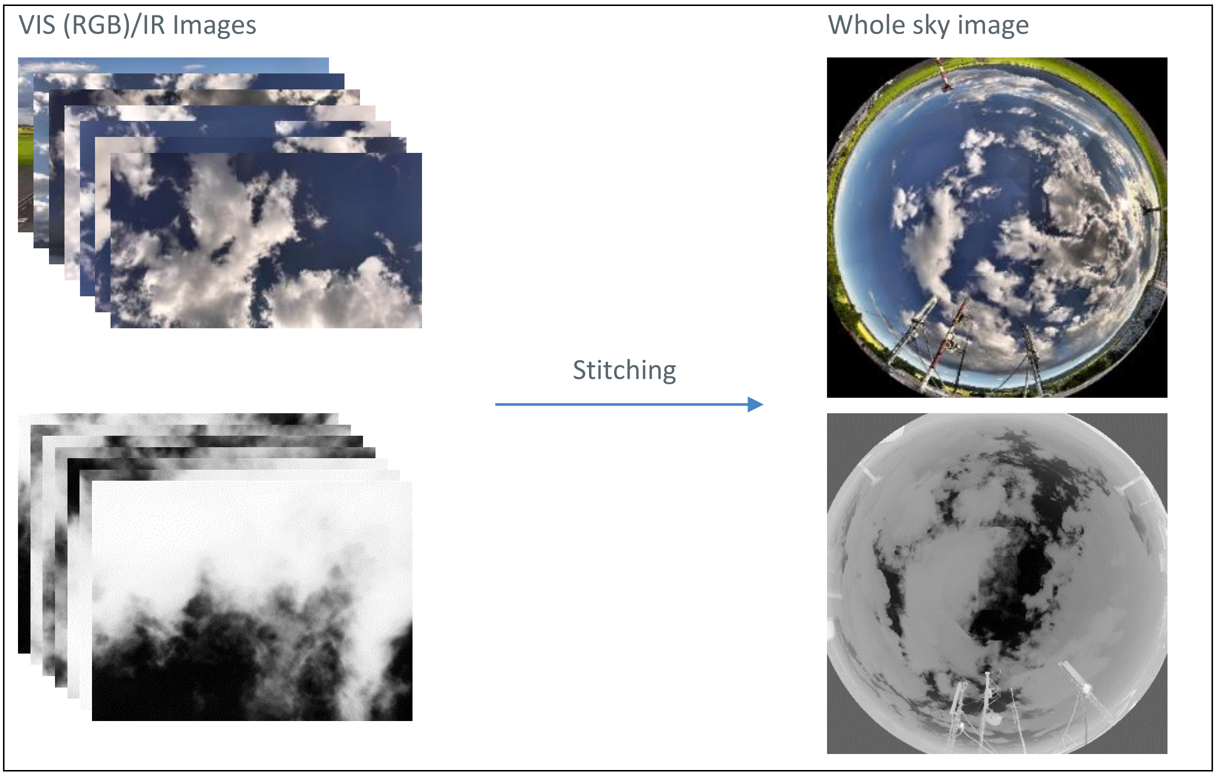

Figure 44: Whole sky images

CRT-18-04b-TRL4-TVALP-015.002

For this success criterion, the following hypothesis was postulated: "*Camera provided series of visibility landmarks imagery suitable for automatic recognition and remote observer observation of prevailing visibility.*"

This success criterion has been fulfilled in the following way:

The Camera takes picture of horizon in all cardinal and intercardinal directions with higher resolution to enable identify visibility landmarks (or visibility points) by MET Observer or computer-based picture recognition algorithms. However, visibility points for MET Observer are different during day and at night (see Figure 45), and visibility points (resp. areas) for picture recognition (see Figure 46) are even different. The series of visibility points pictures (regardless the type of visibility points) in all directions are available each 10 minutes.

Figure 45: Horizon picture with visibility points for MET Observer during day (left) and night time (right)

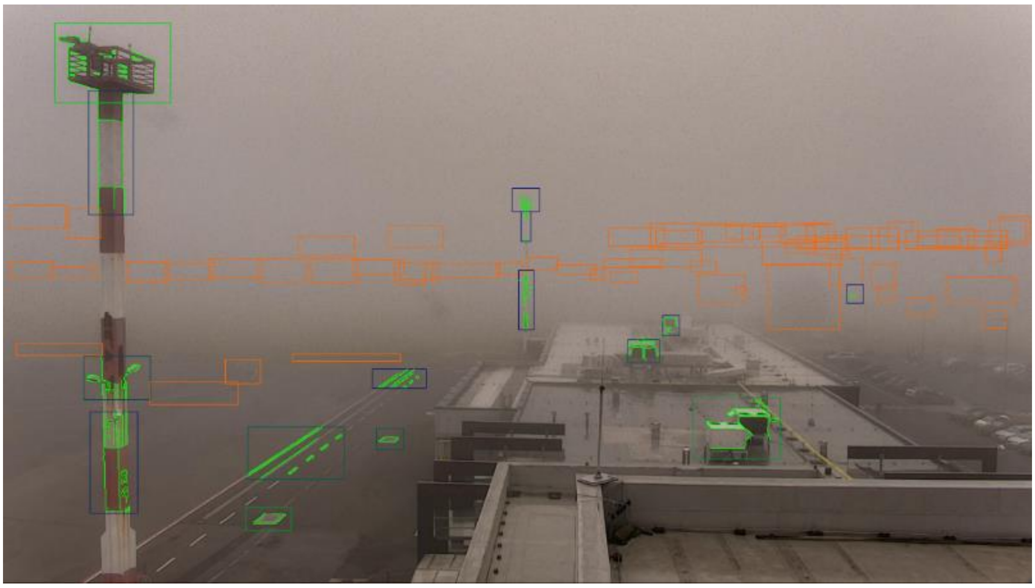

Figure 46: Horizon picture with visibility points for picture recognition algorithm

<u>CRT-18-04b-TRL4-TVALP-015.003</u>

For this success criterion, the following hypothesis was postulated: "*Camera provided video sequences of phenomena.*"

This success criterion has been fulfilled in the following way:

The camera records regularly in 10 minutes interval short (10 seconds) video of reference area to support recognition of some weather phenomena (e.g. precipitation type).

I.3.3 Unexpected Behaviours/Results

No unexpected behaviour/results were recorded during the validation.

I.3.4 Confidence in Results of Validation Exercise

Level of significance/limitations of Validation Exercise Results

Some limitations of camera prototype resulted from lower quality of images during night time (e.g. not satisfactory for visibility points recognition using automatic picture recognition methods) and also during some precipitation events while wiper on camera sometimes did not work as expected, which affected quality of images.

Quality of Validation Exercises Results

In order to prove technical feasibility of the camera prototype, the following success criteria has been successfully tested:

- The system takes image of visibility points (whole horizon) with an update rate of 30 and 60 minutes (or more frequently – it was set to 10 minutes during validation and even more frequent scans are possible).
- The system takes image of whole sky with an update rate of 30 and 60 minutes (or more frequently – it was set to 10 minutes during validation and even more frequent scans are possible).
- The system captures short videos (minimum 5-10 sec – it was set to 11s during validation and longer are possible) of phenomena with an update rate of 30 and 60 minutes (or more frequently – it was set to 10 minutes during validation and even more frequent scans are possible).
- Images and videos from camera are captured at one location representative for the airport and its vicinity.
- Camera has the capability to rotate in predefined repeatable cycles.
- Camera has the capability to tilt in predefined repeatable cycles.
- Camera has the capability to rotate/tilt/zoom in non-regular scans.
- Camera has the capability to extract both video and imagery in both predefined repeatable cycles and non-regular scans.
- Prototype is able to create single sky picture from multiple partial images of sky from different tilts and rotations of camera.
- Prototype is able to blur/remove sensible content from images.[6]

Verification process is documented in respective Availability Note [74] prior to validation exercise in Solution Pj.05-05, which has been supported by this activity.

Two different types of camera has been tested to provide required VIS and IR images.

Significance of Validation Exercises Results

Validation exercise of “Airport MET Camera” was Site Acceptance Test at Poprad Airport LZTT, where the camera prototype has been installed. It was performed just before start of validation exercise in Solution Pj.05-05, which required VIS and IR camera imagery for detection of cloud/ visibility/phenomena.

[6] Sensitive content on images from camera was unrecognizable even manually by human (it was always too far away from camera) so in general there was no sensitive content to be detected and blurred/removed from images by prototype.

I.3.5 Conclusions

Camera is capable itself to rotate and tilt to capture images of whole sky in VIS and IR spectrum for clouds observation, images of horizon for visibility points recognition and also short video to support observation of some weather phenomena. It provides valuable inputs to detection of cloud/ visibility/phenomena at an airport and thus contributes to enhancement of MET awareness (even at airports without human MET observer) and supports MET Observer (even at remote location) in current weather observations.

The prototype is technically feasible and ready to support Solution Pj.05-05 validation exercise.

I.3.6 Recommendations

It is recommended in next phases to deal with wiper problem and to enhance quality of horizon images (for visibility point recognition) using optical zoom of camera.

Appendix J Technical Validation Exercise #10 Report (EXE-PJ18-04b-TRL6-001_DLR "Cb-global capabilities")

J.1 Summary of the Technical Validation Exercise #10 Plan

As in the TVALP 18-04b.

J.2 Technical Validation Exercise #10 description and scope

Within this exercise a number of historical cases were examined where the real flown flight routes of aircraft in thunderstorm situations are available. For each of these cases, Cb-global data were reproduced, and it was investigated whether a safer and more efficient flight route could have been planned well in advance, if Cb-global data would have been available to the pilot. In particular, the goal was to show that Cb-global

- raises situational awareness (shared in the air and on the ground)
- contributes to optimize (precautionary) measures during flight
- enables the planning of smart flight routes that avoid a waste of fuel
- contributes to reduce costs

The exercise was performed at DLR premises with indirect involvement of SESAR2020 and external partners. Cb-global data have successfully been provided to the EXEs in PJ18-04c [50][51]. In addition, thunderstorm observations from pilots provided by Thales Avionics within PJ18-04b have been examined with Cb-global, and the feedback regarding the significance of Cb-global data and the recommendations and conclusions drawn have been included in this report.

J.3 Summary of Exercise #10 Technical Validation Objectives and success criteria

Below the details are listed about Validation objectives, related requirements and the success criteria applicable to the objective.

[OBJ]

Identifier	OBJ-18-04b-TRL6-TVALP-016
Objective	To show that the use of the detection and nowcasting of Cb, CIT, and HAIC information from Cb-global contributes to flight safety
Title	Cb-global contributes to flight safety
Category	Safety
Key environment conditions	En-route adverse weather conditions related to Cb
TRL Phase	TRL6

Identifier	OBJ-18-04b-TRL6-TVALP-017
Objective	To show that the use of the detection and nowcasting of Cb, CIT, and HAIC information from Cb-global contributes to fuel savings
Title	Cb-global contributes to fuel efficiency
Category	performance, safety
Key environment conditions	En-route adverse weather conditions related to Cb
TRL Phase	TRL6

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	18-04c TS/IRS DEP_18.04b_0x1
<COVERS>	<ATMS Requirement>	18-04c TS/IRS DEP_18.04b_1x1
<COVERS>	<ATMS Requirement>	18-04c TS/IRS DEP_18.04b_2x1

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL6 TVALP-016.001	At least one example where Cb-global information contributes to flight safety
CRT-18-04b-TRL6 TVALP-017.001	At least one example where Cb-global information contributes to fuel savings

J.4 Summary of Technical Validation Exercise #10 Validation scenarios

Reference scenario:

The original flown flight routes for specific thunderstorm situations for which the planning was performed without the Cb-global capability.

Solution scenario

Identified possible alternative routes, if Cb-global thunderstorm detections and nowcasts are available for the flight planning.

J.5 Summary Technical Validation Exercise #10 Assumptions

No specific assumptions have been made.

J.6 Deviation from the planned activities

No deviations occurred.

J.7 Technical Validation Exercise #10 Validation Results

J.7.1 Summary of Technical Validation Exercise #10 Results

Technical Validation Exercise #10 Validation Objective ID	Technical Validation Exercise #10 Validation Objective Title	Technical Validation Exercise #10 Success Criterion ID	Technical Validation Exercise #10 Success Criterion	Technical Validation Exercise #10 Results	Technical Validation Exercise #10 Validation Objective Status
OBJ-18-04b-TRL6-TVALP-016	Cb-global contributes to flight safety	CRT-18-04b-TRL6 TVALP-016.001	At least one example where Cb-global information contributes to flight safety	For historical events it could be shown that Cb-global provides the situational awareness of the thunderstorm situation, and enables the pilot to optimize the measures to be taken (e.g. plan a safe route around the thunderstorms)	OK
OBJ-18-04b-TRL6-TVALP-017	Cb-global contributes to fuel efficiency	CRT-18-04b-TRL6 TVALP-017.001	At least one example where Cb-global information contributes	A statistics has been established and real flown flight routes have been compared with flight	OK

Technical Validation Exercise #10 Validation Objective ID	Technical Validation Exercise #10 Validation Objective Title	Technical Validation Exercise #10 Success Criterion ID	Technical Validation Exercise #10 Success Criterion	Technical Validation Exercise #10 Results	Technical Validation Exercise #10 Validation Objective Status
			to fuel savings	routes optimized on the basis of Cb-global information. Both show considerable fuel savings if Cb-global is used for the flight planning	

Table 18: Technical Validation Results Exercise #10

Results on technical feasibility

Cb-global is an intelligent and computational efficient technology using different spectral channels of geostationary satellite data in order to identify four stages of convective hazard levels: 1) potential convective cloud development, 2) rapid vertical cloud growth, 3) mature thunderstorm (Cb), and 4) convectively induced turbulence (CIT). For all these stages, a nowcasting of the individual convective cells can be provided up to one hour in five minutes steps, and specific characteristics of the convective cells can be output like e.g. cloud top height, moving speed, moving direction, and trend. It could also be shown for some cases (see results for OBJ-18-04b-TRL6-TVALP-016 below) that Cb-global can also detect high altitude icing conditions (HAIC). However, a systematic proof of the HAIC detection with Cb-global has still to be performed.

Cb-global is able to process data from different geostationary satellites covering the whole globe (see table and Figure 47 below):

Satellite	Spatial resolution	Temporal resolution
METEOSAT 10 METEOSAT 11	Up to 1.5 km	5 minutes (METEOSAT 10) for Europe 15 minutes (METEOSAT 11) outside Europe

METEOSAT 8 IODC	Up to 1.5 km	15 minutes
HIMAWARI 8	Up to 500 m	10 minutes
GOES-E	Up to 500 m	5 or 15 minutes, depending on region
GOES-W (from year 2020)	Up to 500 m	5 or 15 minutes depending on region

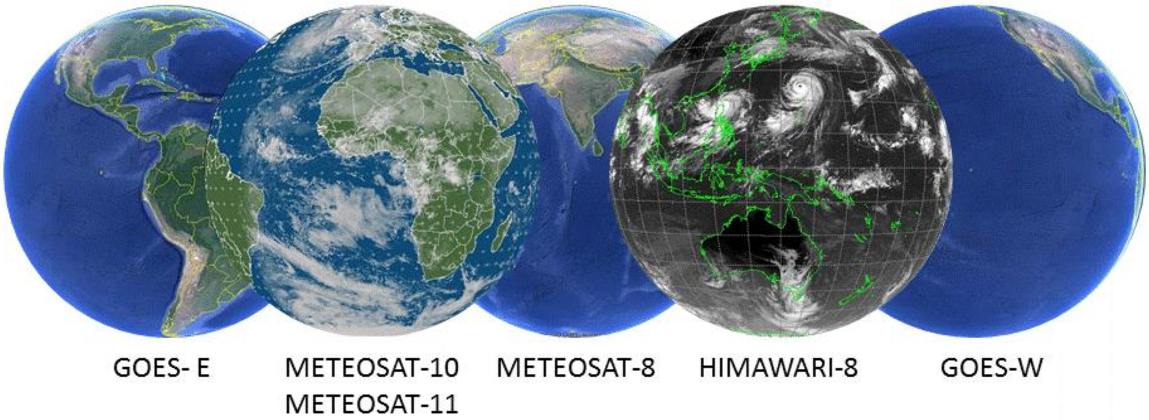

Figure 47: Cb-global coverage

The Cb-global thunderstorm detection and nowcasting up to one hour is possible all over the globe in a spatial resolution of up to 500 m and an update rate of up to 5 minutes. The huge data amount of satellite observations (up to 600 Mbytes per satellite and update) is processed within 1-2 minutes by an efficient and intelligent algorithm which extracts the relevant information (convective cells, their nowcasts, and their characteristics) and outputs it in a SWIM compatible GML/XML standard output. The output can be compressed to very small data amounts that are suitable for uplink into the cockpit of aircraft via ACARS, Iridium and other SATCOM IP uplink technologies.

Figure 48 shows a Cb-global example over Indonesia (Himawari -8 satellite):

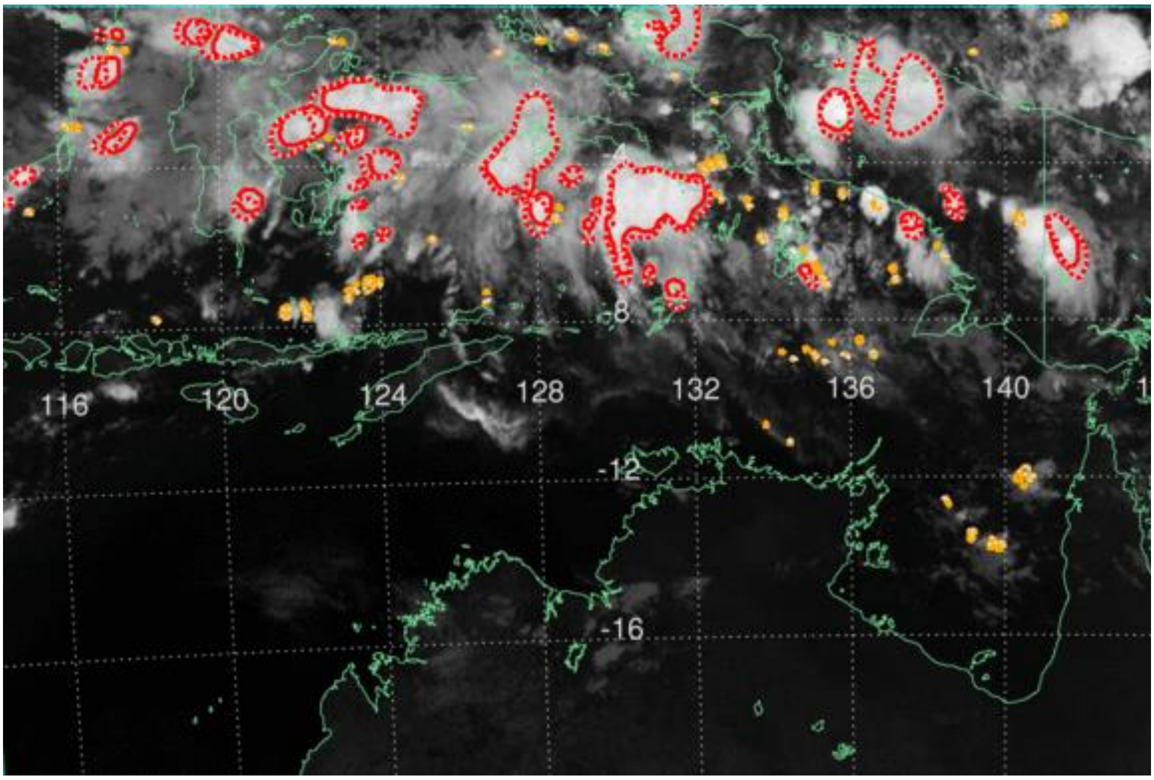

Figure 48: Identified (bold contours) and nowcast (dashed contours) Cb-global cells over Indonesia

Orange colour indicates rapidly developing clouds, red colour indicates mature thunderstorms. Background is a satellite image with copyright by Japan Meteorological Agency.

Figure 49 shows another example with thunderstorms over South Africa (METEOSAT-11 satellite):

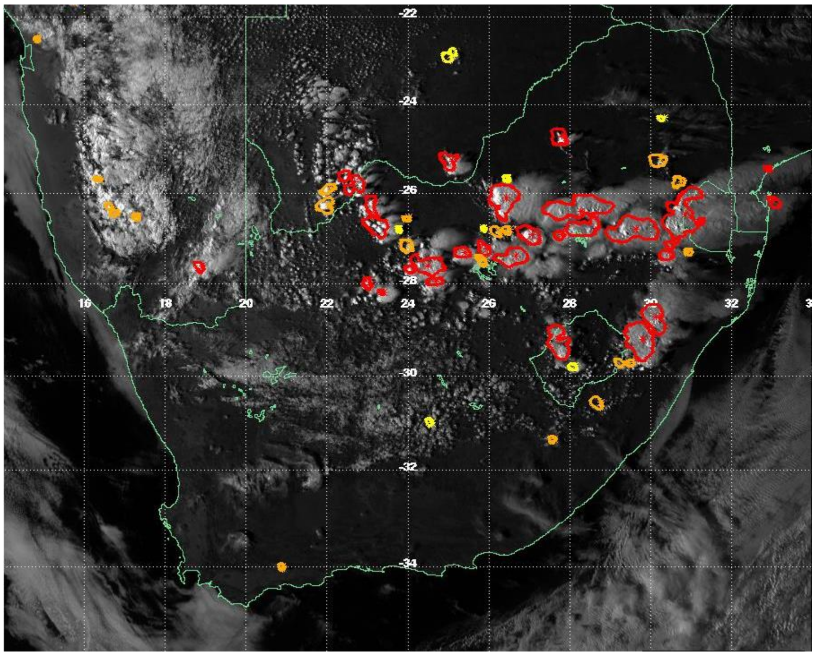

Figure 49: Identified (bold contours) Cb-global cells over South Africa

Yellow colour indicates potential convective cloud development, orange colour indicates rapidly developing clouds, and red colour indicates mature thunderstorms. Background is a satellite image with copyright by EUMETSAT.

Figure 50 shows a nice example over South India and the Indian Ocean with different convective hazard levels also including stage 4 (CIT). CIT is not related to lightning incidents, but often occurs in the vicinity of mature storms or in frontal systems where vigorous updrafts occur like e.g. in the cyclone approaching south-western India.

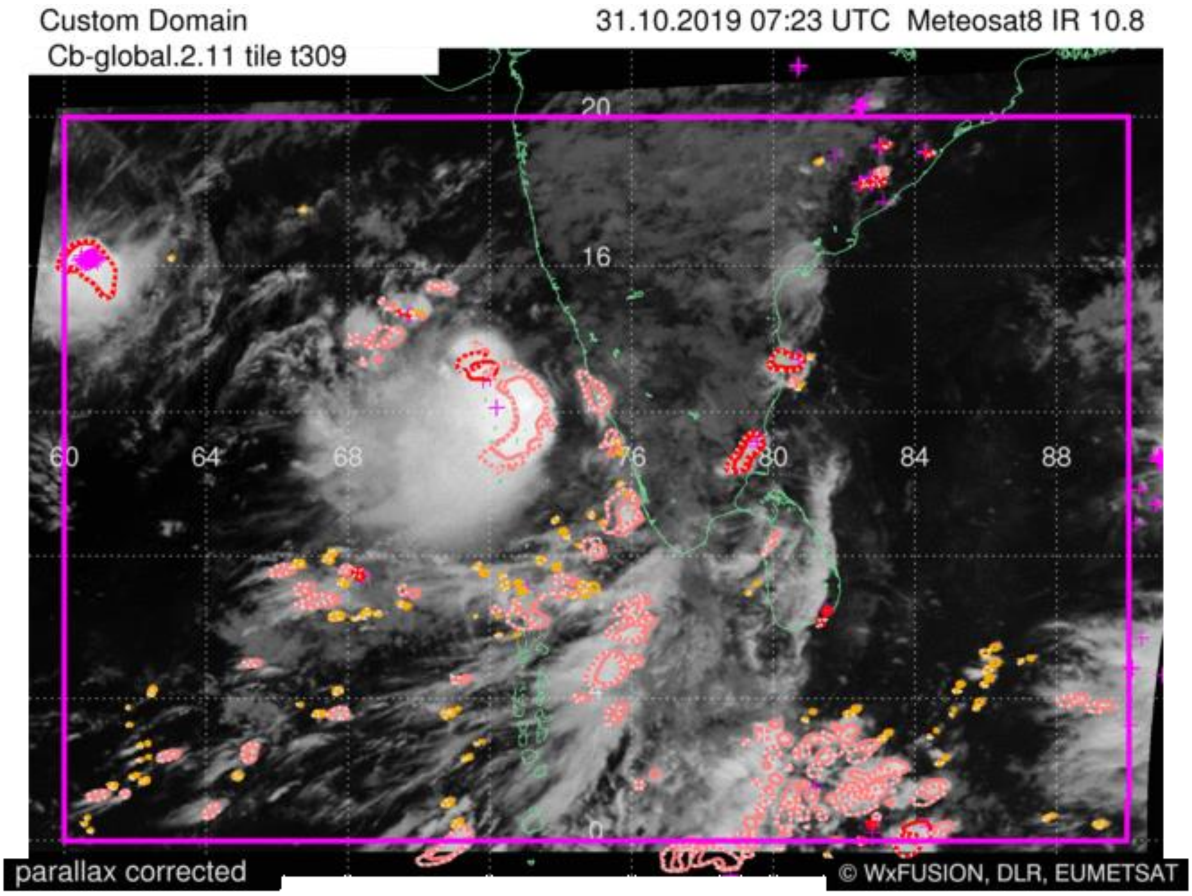

Figure 50: Identified (bold contours) Cb-global cells over South India, Sri Lanka, and the Indian Ocean

Yellow colour indicates potential convective cloud development, orange colour indicates rapidly developing clouds, red colour indicates mature thunderstorm, and pink colour indicates CIT. Single lightning incidents are marked by magenta crosses. Background is a satellite image with copyright by EUMETSAT.

Figure 51 shows a screenshot of a part of a Cb-global GML/XML-file.

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            12.3261 72.6172 12.5875 72.6595 12.6772 72.7806 12.8002 73.0859 12.8026 73.1935 12.7752 73.2604 12.5447 73.3288 12.3751 73.5156 12.3759 73.5516 12.2620 73.6404 12.0877 73.6118 11.9700 73.5210 11.9128 73.5476
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Figure 51: screenshot of a part of a Cb-global GML/XML-file

Results per KPA

The current exercise does not provide results per KPA.

J.7.2 Analysis of Exercise #010 Results per Technical Validation objective

For this exercise more than 30 thunderstorm cases were explored, most of them over the South Atlantic and over Africa due to the availability of satellite data in the DLR archive. For all of these cases the original flown flight routes were available from the IAGOS data base (https://www.iagos.org/), i.e. for all of these cases we have the reference scenario available (flight route flown without Cb-global information). Cb-global information was reproduced for all of these cases, and alternative routes that are safer and more fuel efficient were identified based on the Cb-global information.

In addition, thunderstorm observations from pilots provided by Thales Avionics within PJ18-04b have been examined with Cb-global, and the feedback regarding the significance of Cb-global data and the recommendations and conclusions drawn have been included in this.

For the description of the results per technical validation objective below, we chose one prominent example from our examined cases in order to show that Cb-global contributes to flight safety (OBJ-18-04b-TRL6-TVALP-016) and efficiency (OBJ-18-04b-TRL6-TVALP-017). This case has also been described in [60][61].

OBJ-18-04b-TRL6-TVALP-016 Results

The chosen example is an IAGOS flight over the Central Atlantic for a flight from Rio de Janeiro to Frankfurt on 4 February 2013 (Figure 6, original flight route in yellow) for which we have direct feedback from the pilots and for which the data link technology to uplink Cb-global data during flight was available for testing [60][61] Originally, the pilots had planned to fly the route along the waypoints SAKSI – OBKUT – DEKON, but when they arrived at SAKSI they saw in the on-board radar that this route was blocked by a line of massive thunderstorms. They decided to deviate to the east, because the SigWx charts traditionally used for the flight planning indicated less Cb activity there. Due to the limited view of the on-board radar they could not see the gaps between the individual Cb cells (e.g. on the SALPU – ORARO- TASIL route) and continued their eastward heading. Finally, they decided to uplink the Cb-global data when they had crossed the NOISE – BRETU –MIKOL line. With Cb-global they obtained the overview of the situation and could see the gap close to the DIGOR – KOGUS route. They decided to turn the aircraft by 90°, verified the gap shown by Cb-global with their on-board radar, and based on the combination of the information from Cb-global and the on-board radar they could find their way through.

IAGOS measurements of ice particle numbers that were taken during this flight showed very low particle number concentrations, i.e. there were no in-flight or ice-crystal icing conditions even on the way through the gap shown by Cb-global. We conclude therefore that the route taken by the pilots based on the Cb-global information was safe with regard to thunderstorm (Cb), turbulence (CIT), and icing hazards (HAIC):

CRT-18-04b-TRL6 TVALP-016.001 (At least one example where Cb-global information contributes to flight safety) has been reached.

Similar results regarding HAIC could be obtained from an analysis of the other 29 thunderstorm cases. A scientific publication on these results is in progress and will presumably be ready for submission by the beginning of 2020.

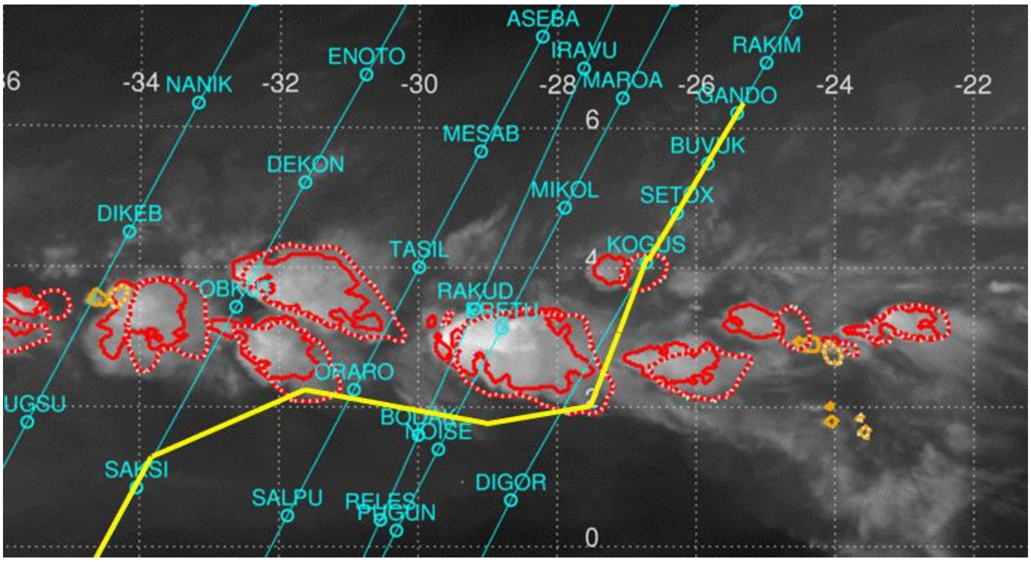

Figure 52: Thunderstorm cells over the Central Atlantic for the flight on 4 February 2013 identified (bold red contours) and nowcast (dashed contours) by Cb-global.

Waypoints and typical trans-Atlantic flight routes are plotted in cyan. Backgournd is a satellite image with copyright by EUMETSAT.

OBJ-18-04b-TRL6-TVALP-017 Results

In a post analysis, the pilots investigated the fuel consumption during the flight on 4 February 2013 presented above. Result: If they would have uploaded the Cb-global information already at waypoint SAKSI, they could have taken the gap on the PUGSU – DIKEB or the SALPU – ORARO -TASIL route and saved a 300 nautical miles deviation or approximately 2 tonnes of fuel[60][61].

CRT-18-04b-TRL6 TVALP-017.001 (At least one example where Cb-global information contributes to fuel savings) has been reached.

When comparing the fuel consumption of the real flown flight routes of the remaining 29 flights with the fuel consumption for the flight routes optimized on the basis of Cb-global information we obtained the following results:

- Some cases result in a fuel saving potential up to 3 tonnes per flight
- some avoidance manoeuvers were not necessary at all
- landings at alternates can be avoided

Finally, we established a Cb-global statistics for the Central and South Atlantic and combined it with flight statistics. We checked how often the typical flight routes over the Central and South Atlantic are blocked by thunderstorms on average and estimated an average fuel saving potential, if Cb-global is used to optimize the deviation routes. It turned out that the fuel saving is approximately 0,548 tonnes per flight. The results of the validation EXE have been presented at the DACH 2019 conference[62]. In addition, a scientific publication of these results is in progress and will presumably be ready for submission by the end of 2019.

J.7.3 Unexpected Behaviours/Results

No unexpected behaviours or results occurred.

J.7.4 Confidence in Results of Validation Exercise #10

Level of significance/limitations of Technical Validation Exercise Results

The validation EXE (EXE-PJ18-04b-TRL6-001) has proofed the capabilities and high significance of Cb-global. In particular, it could be shown that Cb-global

- raises situational awareness
- contributes to optimize (precautionary) measures during flight
- enables the planning of smart flight routes that avoid a waste of fuel
- contributes to reduce costs

With growing air traffic and increasing thunderstorm activity and intensity in a changing climate, the significance of the use of Cb-global information will even more increase.

Quality of Technical Validation Exercises Results

The exercise has been performed with highest diligence according to scientific standards and with modern technologies of the latest state-of-the-art. We are therefore confident that the results are robust and of excellent quality.

Significance of Technical Validation Exercises Results

The validation results with Cb-global (EXE-PJ18-04b-TRL6-001) highlight what can be done with satellite data today regarding the situational awareness and the nowcasting of hazardous phenomena for aviation like thunderstorms, convectively induced turbulence, and icing conditions. The Cb-global information gives an overview of the hazard situation and its severity. However, it also extends the limited view of the on-board radar by providing a broader picture of the areas that are free of hazards. It happens that a situation identified as hazardous on-board is exposed as harmless by the view of the satellite, i.e. the precautionary measures the have to be taken in hazardous situations can be optimized by using the satellite view as an additional information. The use of Cb-global as an additional strategic planning tool thus results in an operational benefit. This benefit will even increase, if the Cb-global information is used both in the air and on the ground for a common information sharing (CIS) and common decision making (CDM).

J.7.5 Conclusions

Conclusions on technical feasibility

The exercise has shown that it is technically feasible to provide detections and nowcasting of thunderstorms on a worldwide scale. The capability has reached TRL 6.

Conclusions on performance assessments

The satellite-based Cb-global technology provides an overview of the observed thunderstorm situation and a nowcasting up to one hour worldwide. It can be used as an additional planning tool by Airlines (pilots and dispatch) and ANSPs (flight plans and flight control) in the air and on the ground enabling common information sharing (CIS) and common decision making (CDM) and finally resulting in a monetary benefit for all stakeholders, since operations can be optimized and flights can be performed more efficient e.g. with regard to fuel consumption.

J.7.6 Recommendations

- Training for pilots: They have to learn how to combine the on-board information with the information provided by Cb-global and include it in their decision making process

- Design means for pilots: New beneficial measures for flight planning have to be defined that account for the availability of real time hazard information. This could be a task for SESAR2020 Wave 2 (e.g. within PJ18W2 Sol .57)

Appendix K Technical Validation Exercise #11 Report (EXE-PJ18-04b-TRL6-002_DLR "Cb-global yellow profile service")

K.1 Summary of the Technical Validation Exercise #11 Plan

As in the TVALP 18-04b.

K.2 Technical Validation Exercise #11 description and scope

Within the exercise historical thunderstorm situations have been selected in close cooperation with the PJ18-04c partners. For these historical cases Cb-global has been operated as if it would provide the data for these cases in near real time mode. Standard and SWIM compatible Cb-global GML/XML data were generated and transferred to an https interface with a 15 minutes update rate. Partners from PJ18-04c grabbed the data from the https platform and used it as input for their validation EXE [50][51].

Goal was to show that Cb-global information is transferred via a yellow profile service to a provider of up- and downlink services (partners in PJ18-04c).

K.3 Summary of Exercise #11 Technical Validation Objectives and success criteria

Below the details are listed about Validation objectives, related requirements and the success criteria applicable to the objective.

[OBJ]

Identifier	OBJ-18-04b-TRL6-TVALP-019
Objective	To build a service that delivers Met hazard information via a yellow profile to an Aircraft and Flight Specific Met Integration System
Title	Cb-global yellow profile service
Category	technical feasibility
Key environment conditions	En-route adverse weather conditions related to Cb
V Phase	TRL6

[OBJ Trace]

Relationship	Linked Element Type	Identifier
<COVERS>	<SESAR Solution>	PJ.18-04b
<COVERS>	<ATMS Requirement>	18-04c TS/IRS DEP_18.04b_0x1
<COVERS>	<ATMS Requirement>	18-04c TS/IRS DEP_18.04b_1x1

<COVERS>	<ATMS Requirement>	18-04c TS/IRS DEP_18.04b_2x1

[OBJ Suc]

Identifier	Success Criterion
CRT-18-04b-TRL6 TVALP-019.001	Cb-global information is transferred via a yellow profile service to a provider of up- and downlink services

K.4 Summary of Technical Validation Exercise #11 Validation scenarios

Reference scenario:

No Cb-global yellow profile service is available

Solution scenario

Yellow profile service exists that provides Cb-global data to an https platform where they are picked up by an Aircraft and Flight Specific Met Integration System (e.g. by EXEs performed in PJ18-04c).

K.5 Summary Technical Validation Exercise #11 Assumptions

No specific assumptions have been made.

K.6 Deviation from the planned activities

No deviations occurred.

K.7 Technical Validation Exercise #11 Validation Results

K.7.1 Summary of Technical Validation Exercise #11 Results

Technical Validation Exercise #11 Validation Objective ID	Technical Validation Exercise #11 Validation Objective Title	Technical Validation Exercise #11 Success Criterion ID	Technical Validation Exercise #11 Success Criterion	Technical Validation Exercise #11 Results	Technical Validation Exercise #11 Validation Objective Status
OBJ-18-04b-TRL6-TVALP-019	Cb-global yellow	CRT-18-04b-TRL6 TVALP-019.001	Cb-global information is transferred	Cb-global has been operated in real time mode and	OK

	profile service		via a yellow profile service to a provider of up- and downlink services	transferred GML/XML files to an https interface where partners from PJ18-04c grabbed the data and used it as input for their validation EXE ([51] and [52])	

Table 19: Technical Validation Results Exercise #11

Results on technical feasibility

Cb-global is able to detect and nowcast thunderstorm cells over selected areas efficiently enough that they can be provided in real time mode. The delay between the observation by satellite and the availability of the data on the https interface is about 4 minutes depending on the number of detected thunderstorm cells and the selected calculation area. From a technical point of view this is the optimum that can be reached with state-of-the-art technologies. This delay time includes the time needed to send the satellite data down to the earth, to quality check the satellite data, to transfer them to DLR, to process Cb-global, and to send the XML-data via secured internet protocol (IP) to the https platform. An example of availability times is given here:

Observation time by satellite:	18:04 UTC
Availability of satellite data on DLR server:	18:06 UTC
Availability of Cb-global XML on https platform (=issue time):	18:08 UTC

Screenshot from the https interface:

WxFUSION_WCB_T_t106_201911010804.xml 01-Nov-2019 08:08 468K

The screenshot shows the file name of the XML-file in blue letters. The time of the file name indicates the date and time of the satellite observation. The time given in black letters is the time of the availability of the XML-file on the https-platform.

Results per KPA

The current exercise does not provide results per KPA.

K.7.2 Analysis of Exercise #011 Results per Technical Validation objective

OBJ-18-04b-TRL6-TVALP-019 Results

In total, five use cases have been selected by the PJ18-04c partners, and for each of these cases Cb-global was run in real time mode to provide regular updates of the GML/XML-data on the https platform every 15 minutes. The service was operated for several months and supported the exercises of PJ18-04c [50][51]. In [51] it is documented that the Cb-global GML/XML files could successfully be picked up from the https platform and have been further processed in the data management system of the Civil AU operations centre.

Figure 53 below illustrates the function context (NSV-4) diagram where satellite data input comes from External Met Service Providers. These data are then processed by Cb-global within the 4DWxCube in order to identify and nowcast thunderstorms. The Cb-global service then provides the Cb-global data to the flight management at the civil AU Operations Centre.

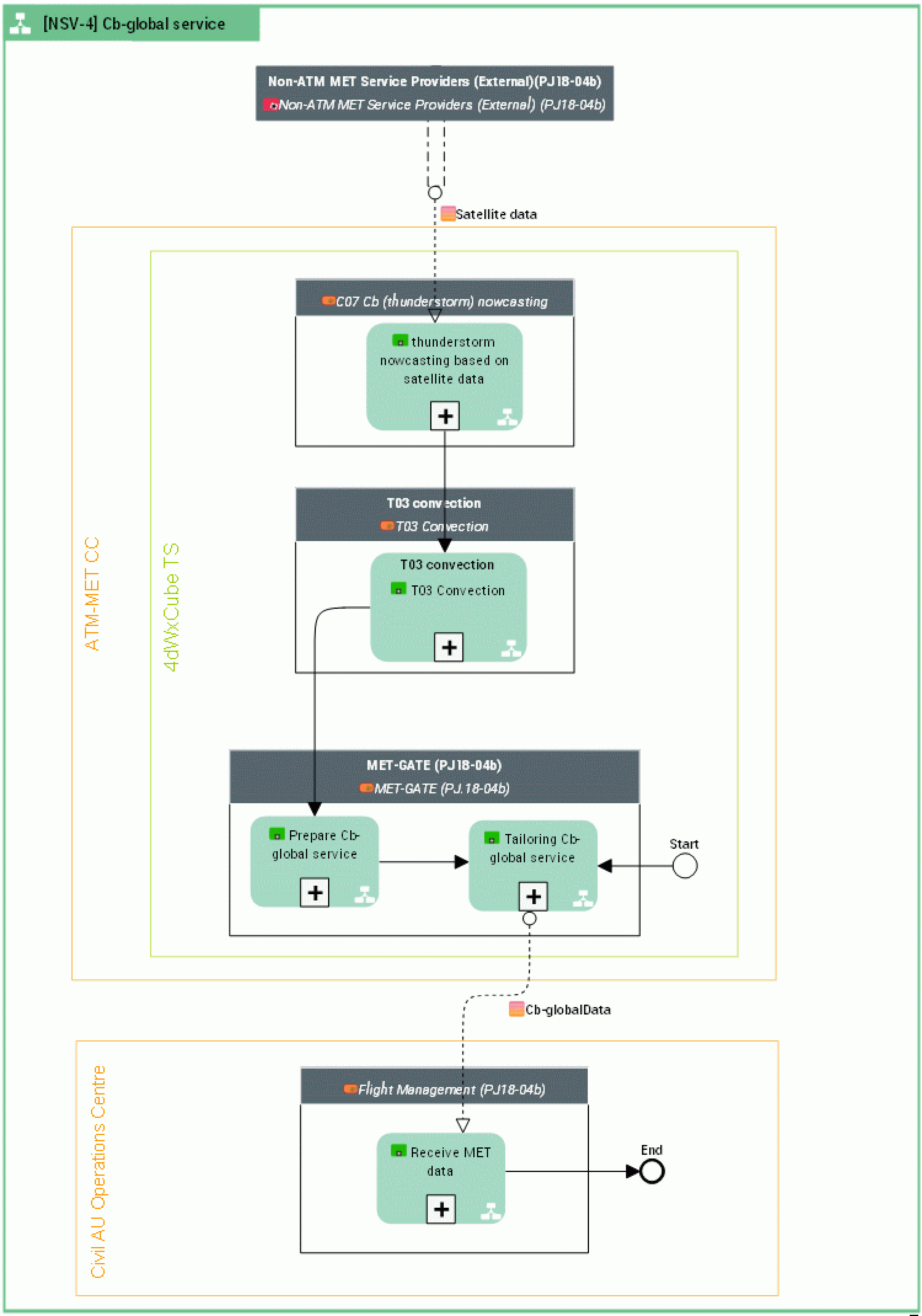

Figure 53: NSV-4 diagram for Cb-global service

```
..............................................
ANALYSIS TIME (UTC) 1:0,    Local Time  1:3
Issue time not yet reached --- we wait
Issue time = 1 : 4
Current time = 1 : 3
Most recent analyis time =  1 : 0
File that has to be copied, when issue time is reached : DLR_WCB_T_ATL_201406191122.xml
..............................................
ANALYSIS TIME (UTC) 1:0,    Local Time  1:4
Issue time is reached --- file will be copied
Issue time = 1 : 4
Current time = 1 : 4
Most recent analyis time =  1 : 0
File /volume/Cb-global-OUTPUT/Honeywell/XML/20140619/DLR_WCB_T_ATL_201406191122.xml has been copied to
web01:/var/www/html/wxfusion/DLH/Cb-global/USECASE_3/Cb-global_XML/20190925/DLR_WCB_T_UC3_201909250107.xml
..............................................
ANALYSIS TIME (UTC) 1:15,    Local Time  1:4
Issue time not yet reached --- we wait
Issue time = 1 : 19
Current time = 1 : 4
Most recent analyis time =  1 : 15
File that has to be copied, when issue time is reached : DLR_WCB_T_ATL_201406191137.xml
..............................................
ANALYSIS TIME (UTC) 1:15,    Local Time  1:5
Issue time not yet reached --- we wait
Issue time = 1 : 19
Current time = 1 : 5
Most recent analyis time =  1 : 15
File that has to be copied, when issue time is reached : DLR_WCB_T_ATL_201406191137.xml
```

Figure 54: Screenshot of one of log-files controlling the transfer of the reproduced historical files to the https platform in real time

K.7.3 Unexpected Behaviours/Results

No unexpected behaviours or results occurred.

K.7.4 Confidence in Results of Validation Exercise #11

Level of significance/limitations of Technical Validation Exercise Results

The results of this validation EXE (EXE-PJ18-04b-TRL6-002) are of high significance, since it has proofed that Cb-global nowcasting of thunderstorms can be provided efficiently and in real time via a yellow profile service to a provider of up- and downlink services with high update rates and very small delay times with regard to the observation. This service enables aviation stakeholders to make use of Cb-global data in their own systems and displays and benefit from these high quality data in their decision making processes.

Quality of Technical Validation Exercises Results

The exercise has been performed with highest diligence according to scientific standards and with modern technologies of the latest state-of-the-art. We are therefore confident that the results are robust and of excellent quality.

Significance of Technical Validation Exercises Results

The validation results with the Cb-global service (EXE-PJ18-04b-TRL6-002) highlight that already today it is technically feasible to provide high quality thunderstorm hazard nowcasting data in real time in a format that allows an uplink into cockpit EFB systems in reasonable time.

K.7.5 Conclusions

Conclusions on technical feasibility

The exercise has shown that it is technically feasible to provide detections and nowcasting of thunderstorms in real time in reasonable time via a yellow profile service without failure. The service has reached TRL 6.

Conclusions on performance assessments

The Cb-global service technology provides a unique opportunity for aviation stakeholders to access high quality real time thunderstorm data on a worldwide scale which can be used as strategic support for the flight planning. The real time availability of Cb-global enables common information sharing (CIS) and common decision making (CDM) and finally brings a monetary benefit for all stakeholders, since operations can be optimized and flights can be performed more efficient e.g. with regard to fuel consumption.

K.7.6 Recommendations

- Cb-global hazard data have to be disseminated and made available to pilots and other aviation stakeholders in order to enable the common evaluation of hazard information from different tools
- Provision of tools that represent and display the hazard information and graphically enable the combination of the hazard information coming from different sources (Cb-global vs. on-board radar)

Appendix L Technical Validation Exercise #12 Report (EXE-PJ18-04b-TRL4-003_DLR “Contrail formation”)

L.1 Summary of the Technical Validation Exercise #12 Plan

As in the TVALP 18-04b.

L.2 Technical Validation Exercise #12 description and scope

Within the exercise, historical meteorological conditions along aircraft trajectories have been selected. For these historical cases contrail formation criteria and contrail persistence have been calculated using on-board aircraft observations from IAGOS-aircraft and meteorological data from reanalysis model (ERA-5) as well as data from chemistry-climate model EMAC. For an individual data point (aircraft position) contrail formation and persistence criteria were evaluated using both IAGOS observational data (on-board aircraft) and atmospheric model data. Using formulas and algorithms presented in **¡Error! No se encuentra el origen de la referencia.** enabled to identify regions where contrails form and regions where persistent contrails form, hence increasing situational awareness relevant for climate impact of aviation.

Goal was to show that both observational data and MET numerical model data enable identification of regions of the atmosphere where contrail can form, and to evaluate differences between two sources of meteorological information, on-board data and numerical weather forecast data.

L.3 Summary of Exercise #12 Technical Validation Objectives and success criteria

Below the details are listed about Validation objectives, related requirements and the success criteria applicable to the objective.

[OBJ]

Identifier	OBJ-18-04b-TRL4-TVALP-018
Objective	To show that areas along the trajectory where (persistent) contrails are formed can be identified by “Contrail formation” MET information
Title	Contrail formation
Category	technical feasibility
Key environment conditions	En route nominal weather conditions
V Phase	TRL4

[OBJ Suc]

Identifier	Success Criterion

CRT-18-04b-TRL4 TVALP-018.001	To provide a set of specific real-world examples when contrail formed and where aircraft measurement were performed.

L.4 Summary of Technical Validation Exercise #12 Validation scenarios

Reference scenario:

No contrail formation service is available

Solution scenario:

Contrail formation service exists providing information on those atmospheric regions where contrails can form and on those atmospheric regions where persistent contrails form.

L.5 Summary Technical Validation Exercise #12 Assumptions

No specific assumptions have been made.

L.6 Deviation from the planned activities

No deviations occurred.

L.7 Technical Validation Exercise #12 Validation Results

L.7.1 Summary of Technical Validation Exercise #11 Results

Technical Validation Exercise #12 Validation Objective ID	Technical Validation Exercise #12 Validation Objective Title	Technical Validation Exercise #12 Success Criterion ID	Technical Validation Exercise #12 Success Criterion	Technical Validation Exercise #12 Results	Technical Validation Exercise #12 Validation Objective Status
OBJ-18-04b-TRL4-TVALP-018	Contrail formation	CRT-18-04b-TRL4 TVALP-018.001	To provide a set of specific real-world examples when contrail formed and where aircraft	Contrail formation has been calculated and regions of persistent contrail formation have been identified, using observational	OK

			measurement were performed.	and reanalysis data.	

Table 20: Technical Validation Results Exercise #12

Results on technical feasibility

Contrail formation service is able to identify regions of the atmosphere where contrails can form and where contrails formed are persistent. As input the algorithm requires atmospheric data on background atmospheric humidity and temperature, as well as engine efficiency and fuel lower heating value, which has been integrated in an empirical formula, the so-called Schmidt-Appleman criterion. IAGOS-Measurement aircraft provide data with a high temporal resolution (4 s), while atmospheric numerical modelling data has a coarser temporal resolution with minutes to hours. Atmospheric model data we were using in the exercise had temporal resolutions 240s, 720s, 1 hour and 6 hour values.

Results per KPA

The current exercise does not provide results per KPA.

L.7.2 Analysis of Exercise #012 Results per Technical Validation objective

OBJ-18-04b-TRL4-TVALP-018 Results

Data for the period March and April 2014 has been evaluated in detail. For the whole period contrail formation was calculated on the MOAZAIC-Flights performed (in total 600 flights). From this set individual characteristic situations were selected to perform a dedicated case study. For these case studies contrail formation was determined by using observational data, as well as numerical weather forecast data with coarser temporal and spatial resolution. These two data sources were selected in order to determine to what extent regions of contrail formation are characterised differently if a different source of MET data is used.

Figure 55 below illustrates a comparison of the Schmidt-Appleman criterion applied to IAGOS data and ERA 5 reanalysis data. A value ≥1 implies that a contrail is formed. Obviously there is a large degree of agreement between the two data sources (Correlation is 0.97). For the question of persistence we find a high correlation between the data (0.78), but for the March 2014 data there is a positive bias in the relative humidity field of ERA 5. We have computed statistical parameters as well. But this is merely an initial step. Further comparisons for other seasons and regions are underway.

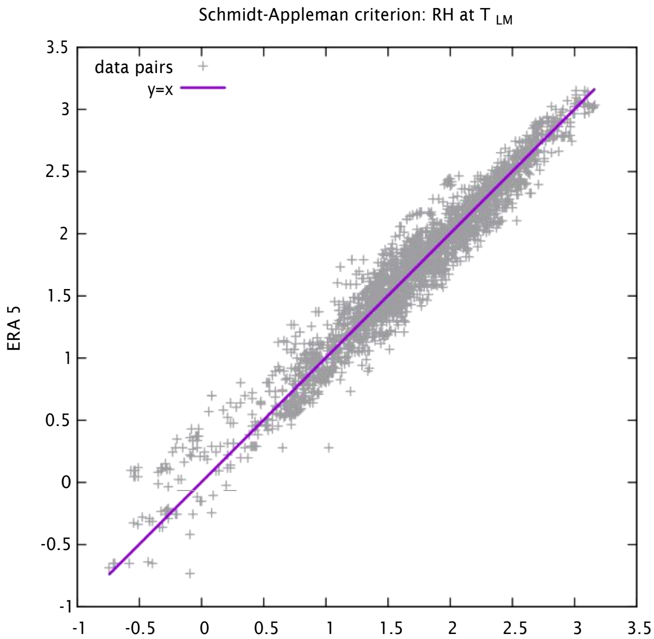

Figure 55: Evaluation of relative humidity at maximum temperature enabling contrail formation TLM evaluating IAGOS observational data and ERA5 reanalysis numerical modelling data on trajectories flown by IAGOS-measurement aircraft in March 2014.

L.7.3 Unexpected Behaviours/Results

No unexpected behaviours or results occurred.

L.7.4 Confidence in Results of Validation Exercise #12

Level of significance/limitations of Technical Validation Exercise Results

The results of this validation EXE (EXE-PJ18-04b-TRL4-003) are significant, since they prove that both observational and numerical weather forecast data allow identification of contrail forming regions in the atmosphere. Such MET service can be used on-board of aircraft as well as in ground based system, using available standard meteorological information. This service enables aviation stakeholders to determine whether an aircraft is flying in a region of contrail formation and persistence, hence it allows quantification of distance contrailling which is an initial step toward climate impact assessment of aircraft operations. The service enhances awareness of the situation, and decision making will benefit from this additional information.

Quality of Technical Validation Exercises Results

The exercise for the specific case studies has been performed with highest diligence according to scientific standards and with modern technologies of the latest state-of-the-art.

Significance of Technical Validation Exercises Results

The validation results with the contrail formation service (EXE-PJ18-04b-TRL4-003) highlight that already today it is technically feasible to provide contrail formation and persistence criteria in a format that allows efficient usage in existing systems having MET data available.

L.7.5 Conclusions

Conclusions on technical feasibility

The exercise has shown that it is feasible to identify contrail forming regions on a worldwide scale by using available MET standard information as input.

Conclusions on performance assessments

The contrail formation service technology provides a unique opportunity for aviation stakeholders to access one aspect of climate impact of aviation along an aircraft trajectory on a worldwide scale which can be used as strategic support for the flight planning. The availability of contrail formation and persistence criteria along aircraft trajectories provides additional information on flight situation relating to environmental impacts of aircraft operations. In case incentives for avoiding contrail-forming regions would be raised, such information is required and needs to be integrated in common information sharing (CIS) and common decision making (CDM). When working towards aircraft operations with less climate impact, such services need to be expanded to provide a quantitative measure of associated climate impact of contrails formed. In case of expanded trading mechanism on climate impact of aviation, beside CO_2, such expanded climate impact relevant information has the potential to bring a monetary benefit for all stakeholders, since operations could be optimized and flights can be performed more efficiently e.g. with regard to fuel consumption while having less impact on environment.

L.7.6 Recommendations

Contrail formation and persistence criteria should be integrated in existing MET systems, in order to implement an initial expansion of MET information available and increasing current situational awareness relevant for developing aircraft operations which have lower climate impact. Establishing efficient pathways to integrate such advance MET services relevant for climate impact of aviation could help to provide the ground for developing climate-optimized or eco-efficient aircraft operations. Such eco-efficient aircraft operations would be optimized according to economic and ecological target functions.

Appendix M Safety Assessment Report (SAR)

PJ.18-04b focuses on evolution of technology and systems, or capabilities that generate or provide new or enhanced MET information. The purpose is to provide information in a new manner (based on SWIM) or with better quality. The activities do not undermine or drastically change the existing MET information provision required for safe operation.

The development of capabilities and information services has taken into account a number of standards or technical specifications, i.e. ICAO Annex 3, SWIM Technical Infrastructure Yellow Profile and Purple Profile. These new capabilities/services as defined in PJ-18-04b TS/IRS is considered safe because meeting the requirements defined by ICAO Annex 3, SWIM technical infrastructure and by the identified SESAR solutions consuming these capabilities/services (e.g. PJ02 for glide path wind profile and etc.)

Appendix N Security Assessment Report (SecAR)

High-level security requirements have been provided in the PJ.18-04b TS/IRS and PJ.18-04b has completed security assessment questionnaire in coordination with PJ.19-04. PJ.18-04b considers that security assessment should be performed by ATM solutions where infrastructure is built for providing the services and capabilities.

Appendix O Human Performance Assessment Report (HPAR)

PJ.18-04b is a technological solution focusing evolution of technology and systems, or capabilities. The activities in PJ.18-04b address information provision and capability development in which the role of human is very limited. The validation exercises validate whether the developed capabilities and services are able to provide the information required, in this process, human intervention is not necessary, therefore consideration of human performance is not needed in this regard.

Appendix P SESAR Technological Solution(s) Maturity Assessment

A self-maturity assessment has been conducted and results can be found in the column M of the attached spreadsheet.

PJ.18-04b
Self-maturity asssme

It should be emphasised that the core of the solution is TRL6 prototypes based on which these self-maturity assessment criteria are considered.

Concern has been raised that METForTAM service claims to be TRL6 but has only been demonstrated in a laboratory and not in TRL6 validation due to the fact that it was integrated in the linked operational solution PJ.04-02 validation exercise (EXE-PJ.04-02-V2.04) which is V2 only.

Nevertheless, for the MET capability and finally service provision, real archived MET data have been emulated using the original interfaces of the sources relevant for the particular airport (Oslo Airport, Radar, AWOS, Ensemble Model) making it transparent to the GWMS, if the real sensors and models are connected or the emulated environment. In a shadow-mode exercise where a live MET data feed is realised from sensors at the airport would also hamper the possibility to put in data for particular MET situations that are meaningful to the operational solution (winter weather in this case). This is something what you can be never planned during shadow-mode trials because no one can say what exact weather you will have when planning the dates for validation exercises. In terms of the technology used this makes no difference to the GWMS. Reception of data, processing, and service provision are the same as in the real environment. Additionally, failures of data sources have been tested already in SESAR 1 where TRL6 has been reached for the backend functions.

In addition, self-maturity assessment is also performed for the TRL4 Bora wind activities.

PJ.18-04b
Self-maturity assessı

Appendix Q High level Economic Appraisal

PJ18-04b is defined as technological solution. Nevertheless, there is not “one” or “the” solution which will be deployed. In SESAR 1 the idea of the 4DWxCube was defined as the only access point for MET information. However, this technical system can also be implemented in different capability configurations from network to airport (local) applications.

On the local scale, depending on the needs of the operational consumer and depending on the available MET infrastructure, different sets of MET capabilities enabling different levels of data payloads SWIM services can be requested in concordance with local circumstances and operational improvements targeted which the respective MET services enable or support. SWIM service provision relies on availability SWIM technical infrastructure. Therefore, no cost estimate can be given by the MET industry (including research institutes for PJ.18-04b) as to the deployment of the systems validated in this document. The MET Service Provider and the ANSP and airport operator must analyse which MET information shall be used and where benefits can be obtained in safety, workload, smoothing of processes, operational handling and finally cost reduction.

High-level economic appraisal for the DLR prototypes Cb-global and Cb-global service

Cb-global and the Cb-global service are both marked ready products (TRL6 and higher). DLR is a research institution which is not allowed to sell products on the market. Therefore, DLR is closely cooperating with its spin-off company WxFUSION who offers Cb-global on the market. Since WxFUSION is not partner in SESAR2020 and due to WxFUSION’s company policy a cost appraisal cannot be given here. In addition, it would not be possible to give a general cost appraisal, since the costs for a Cb-global service strongly depend on the customer, the specific requirements of the customers, the area for which the product shall be provided, the service level, and specific agreements between the provider and the customer.